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Research Paper
INT-292

May 1982

Models for Describing Vertical Crown Development of Lodgepole Pine Stands

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Dennis M. Cole and Chester E. Jensen

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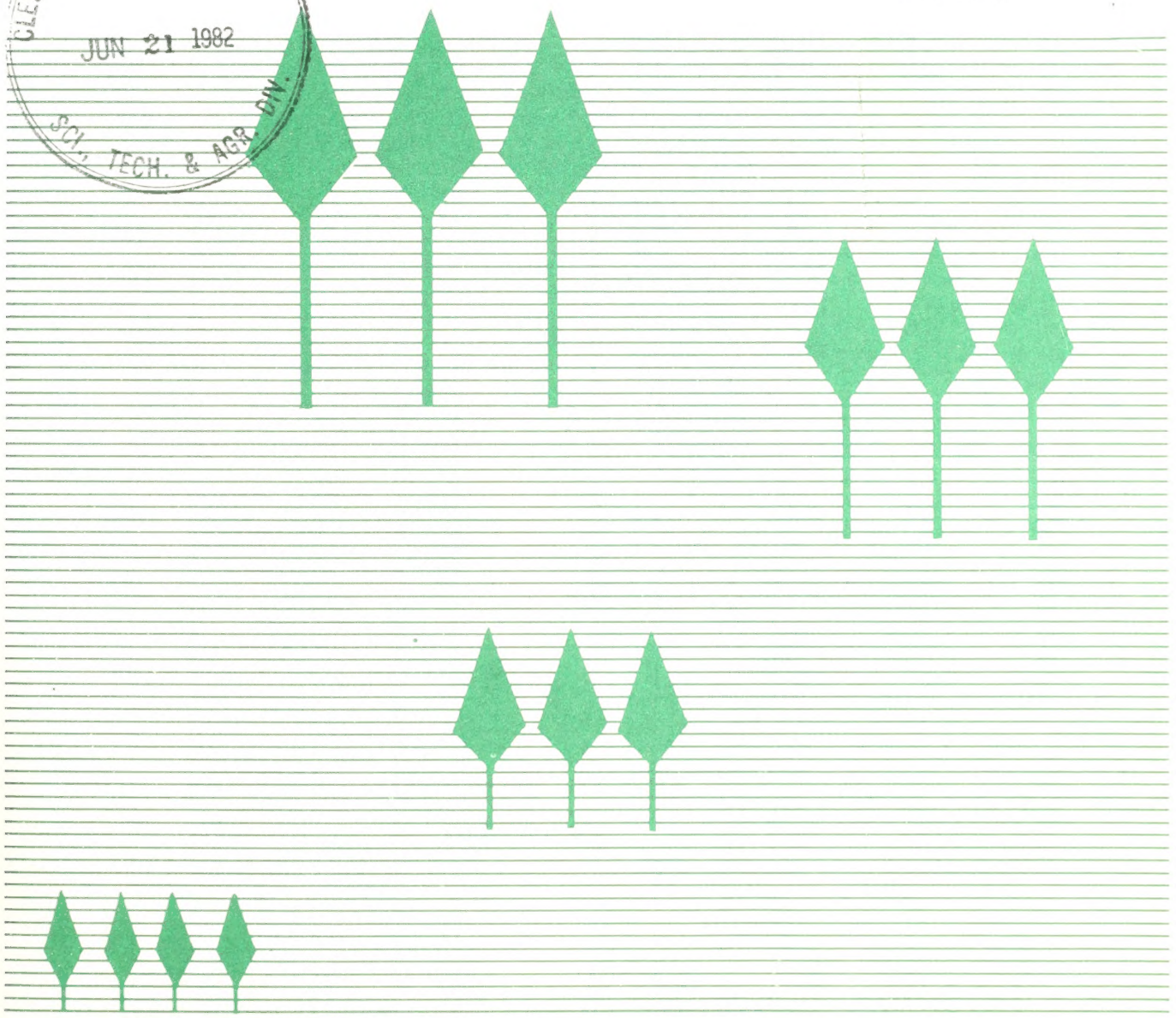

AUTHORS

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CHESTER E. JENSEN, retired, served as principal statistician for the Intermountain Forest and Range Experiment Station from 1967 to 1980. He held the same position at the Northeastern and Central States Forest Experiment Stations prior to going to the Intermountain Station.

RESEARCH SUMMARY

Interaction models for the dominant crown class were developed for estimating average height to base of crowns (crown height) and average crown length (depth) as a function of stand density and average height of dominant trees — for even-aged lodgepole pine stands in Montana, eastern Idaho, western Wyoming, and northeastern Utah. Separate models are presented for two expressions of stand density (basal area, and crown competition factor) to provide analysts an applicable model for existing data bases regardless of which measure of stand density has been used. Tables of model solutions for representative classes of stand density and height are also provided, along with a supplemental regression equation for estimating height and depth of the total canopy as a function of average crown height and total tree height of dominant trees. Finally, suggestions are made for utilizing the models presented in this paper in computerized stand projection programs. An example is given of vertical crown development in relation to other interactive stand parameters and how these parameters can be expected to vary under different stand management strategies.

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Models for Describing Vertical Crown Development of Lodgepole Pine Stands

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INTRODUCTION

Development of tree crowns and stand canopies is of interest to several forestry disciplines. Mensurationists are interested in it in relation to the amount and distribution of growth among bolewood, branchwood, and foliage of trees and stands. Hydrologists and snow scientists want to know how it relates to the reception and flux of moisture within the aerial and subsurface environments of stands. Silviculturists are interested in it as a process associated with the differentiation of stands into social strata and size distributions, such as height and diameter distributions, that can be manipulated by cultural practices to affect crown development and size distributions within the future stand. Similarly, wildlife and fisheries biologists are interested in how crown and canopy characteristics directly or indirectly influence fish and wildlife.

Although most of these interests are relevant to all forest cover types (Society of American Foresters 1980), our interest here is a single species—lodgepole pine (*Pinus contorta* var. *latifolia*)—and the lodgepole pine cover type where it occurs primarily as pure even-aged stands. Within this context, it is recognized that stand density, age, and site quality are major variables influencing canopy variation among stands.

However, the vertical development of crowns in relation to stand density and age has not been adequately described for lodgepole pine (Gary 1978). We believe this is partly because most attention to crown development (regardless of species) has focused on crown length. Although an important parameter, crown length in a majority of past work has been converted from an absolute measurement unit to crown ratio, a dimensionless relative value, which expresses crown length as a fraction or percentage of total tree height. In addition to obscuring dimensional relationships and our ability to associate them, the expression of crown length as a ratio also masks another important facet of crown development—crown position. Because both crown depth (length) and position relative to the ground are important parameters, we believe they should be examined jointly in terms of their interaction with stand density and age. In pursuing these premises, our investigations have led to a better quantification of these relationships through the development of interaction models and associated relationships and procedures for using them.

METHODS

Data were available from 134 permanent sample plots of a long-term study of stand density effects in natural stands of lodgepole pine. The fixed-area plots were located in even-aged, essentially pure lodgepole pine stands across an extensive geographical area from northeastern Utah to northwestern Montana (fig. 1). The stands represent a broad range of stand characteristics. Basal areas ranged from 30 to 250 ft^2 per acre (1.13 to 57.39 m^2/ha), and mean heights of the dominant crown class (Society of American Foresters 1958) ranged from 21 to 83 ft (6.4 to 25.3 m). Stand ages ranged from 22 to 125 years and site indexes (base 100 years) from 50 to 100.

For each plot, mean values of the following variables were available from a 10-tree subsample of the dominant trees on the plot: (1) age at breast height, (2) diameter at breast height (d.b.h.) outside bark, (3) total height, and (4) height to the base of live crown (the crown base was visually balanced to determine the measuring point). To examine the lowest extent of the canopy in relation to the dominant crown class component, 27 of the plots were subsampled to provide mean values of the above-named variables for the suppressed crown class (Society of American Foresters 1958). Plot tallies of all trees divided into 1-inch (2.54-cm) diameter classes were used to compute basal areas. Stand age was determined from increment cores taken at breast height from the 10-tree sample of the dominant crown class, and the stand was checked for the even-aged condition (age range ≤ 20 years) by randomly sampling the age of intermediate and suppressed trees.

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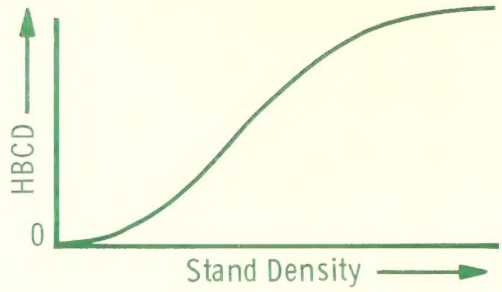
Figure 1.—Geographic distribution of sample plots.

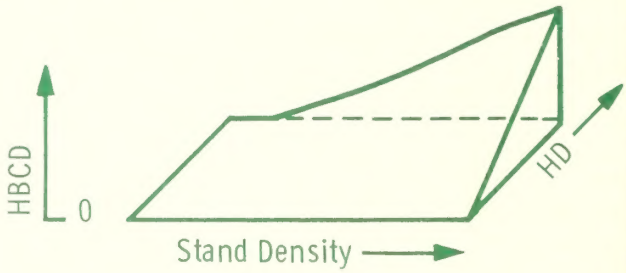
Regression screening of the simple additive effects of basal area (BA), crown competition factor (CCF) (Krajicek and others 1961), average height of dominants (HD), average d.b.h. of dominants (DD), stand age (A), and various transforms and interactions of each, on average height to the base of the crown of dominants (HBCD) revealed reasonably strong, statistically significant ($p = 0.05$) relationships in HBCD = f(BA,HD) and HBCD = f(CCF,HD). A weaker but still significant relationship was also noted for HBCD = f(A,BA).

Because this relationship involved age measured at breast height (A), its use necessitates a conversion to a corresponding total stand age to allow use with stand growth projection programs that project total stand age. For this reason, and the fact that the relationship was weaker, we did not pursue this model. Having established that the relatively simple effects and interactions for BA, CCF, and HD were significant contributions to change in HBCD, potentially more sensitive hypotheses involving these variables were developed. The sources of information for the above were rough expectations, plus finite estimates of interaction developed with half of the data (randomly selected) using the methods of Jensen (1973, 1976, 1979). The basis for expectations and the curve forms postulated are as follows:

In an even-aged stand of lodgepole pine, HBCD is expected to increase sigmoidally upward from zero as stand age and density increases.



Among stands of the same age and site quality, branches near the ground on open-grown trees are not shaded out of existence as they are in more dense stands where trees are competing for light. Thus, at some low to medium density level, shading and HBCD should both begin to increase more rapidly, finally reaching asymtotes at high densities. Among stands of the same age and basal area (where density is high enough that trees are competing for light), differences in site quality can be expected to generate differences in mean dominant tree heights (HD). Because added stand height increases the depth of shade in the stand, the postulated sigmoidal effect of stand density on HBCD is expected to rise in a linear or perhaps relatively flat exponential fashion, with increasing HD.



This major effect may be offset somewhat by the tendency for dominant trees on better sites to maintain lower crown branches longer than their counterparts on poorer sites, all other factors being equal.

The above model was described mathematically and fitted with least squares to the remaining half of the data. It was found by analyses of the residuals to be an effective predictor of that subset of the data. Assuming that a model developed with the same methods on the entire data set would possess more stable parameters, a final model was developed with the combined data for each of two alternative expressions of stand density—basal area (BA) and crown competition factor (CCF) (Alexander and others 1967). Separate models were developed for these two common expressions of lodgepole pine stand density to allow crown depth and position estimates to be made regardless of whether density is expressed as BA or CCF in the data base, or one form or the other is preferred by the analyst.

RESULTS AND DISCUSSION

Applicable Units of Measure

All the mathematical expressions in this paper were developed in English units of measure; therefore, their parameters are applicable and their solutions are correct only with the specified units of the English system.

Average Position and Depth of Dominant Crowns

Basal Area Model

Average height to the base of the crowns of dominant trees (HBCD) was plotted on basal area (BA) by 10-ft (3-m) groups of average dominant tree heights (HD), and the data were found to be distributed such that full sigmoidal effects of basal area (BA) were most apparent in the 30- to 50-ft (9.1- to 15.3-m) HD range (fig. 2). However, because the curve shapes for HBCD over BA were reasonably consistent for all HD groups, they were characterized as a single sigmoidal form[1] operative over the entire range of HD. The maximum heights of the HBCD over BA sigmoids occurred at BA = 250 and defined the upper lim [illegible] (I) and called YP_{BA} [illegible] Jensen an[illegible]

The co[illegible] ly in figure 4. Its n[illegible]

BA

[1] HBCD = YP_{BA} * (1.0019 * e 0.716

where: HBCD = [illegible]

table 1.

[1] The unscaled sigmoidal form for HBCD [illegible]

5.5

250

1.0019 * e 0.716 0.0019

0.9766

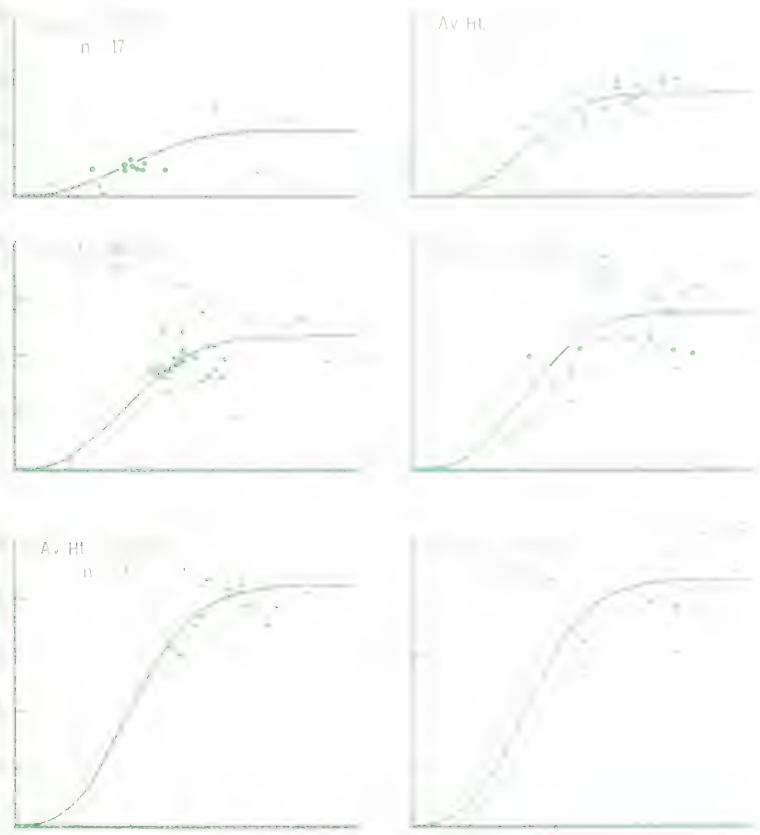


Figure 2.—Sigmoidal effect of BA in HBCD, by tree height groups.

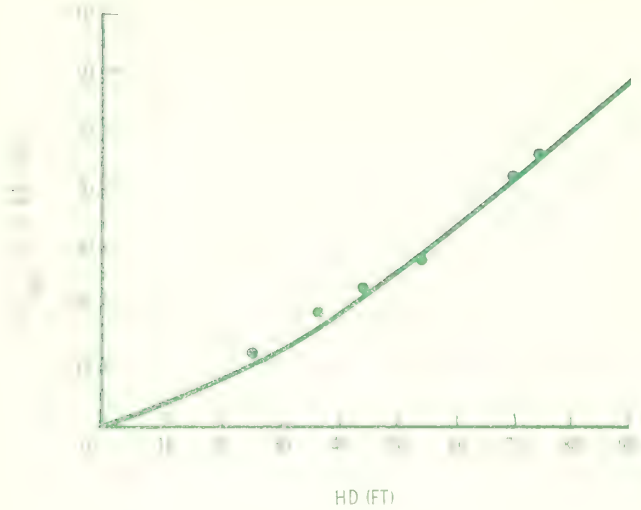


Figure 3.—Maximum height (YP_{BA}) in feet of HBCD over BA sigmoids for the means of 10-foot dominant height classes.

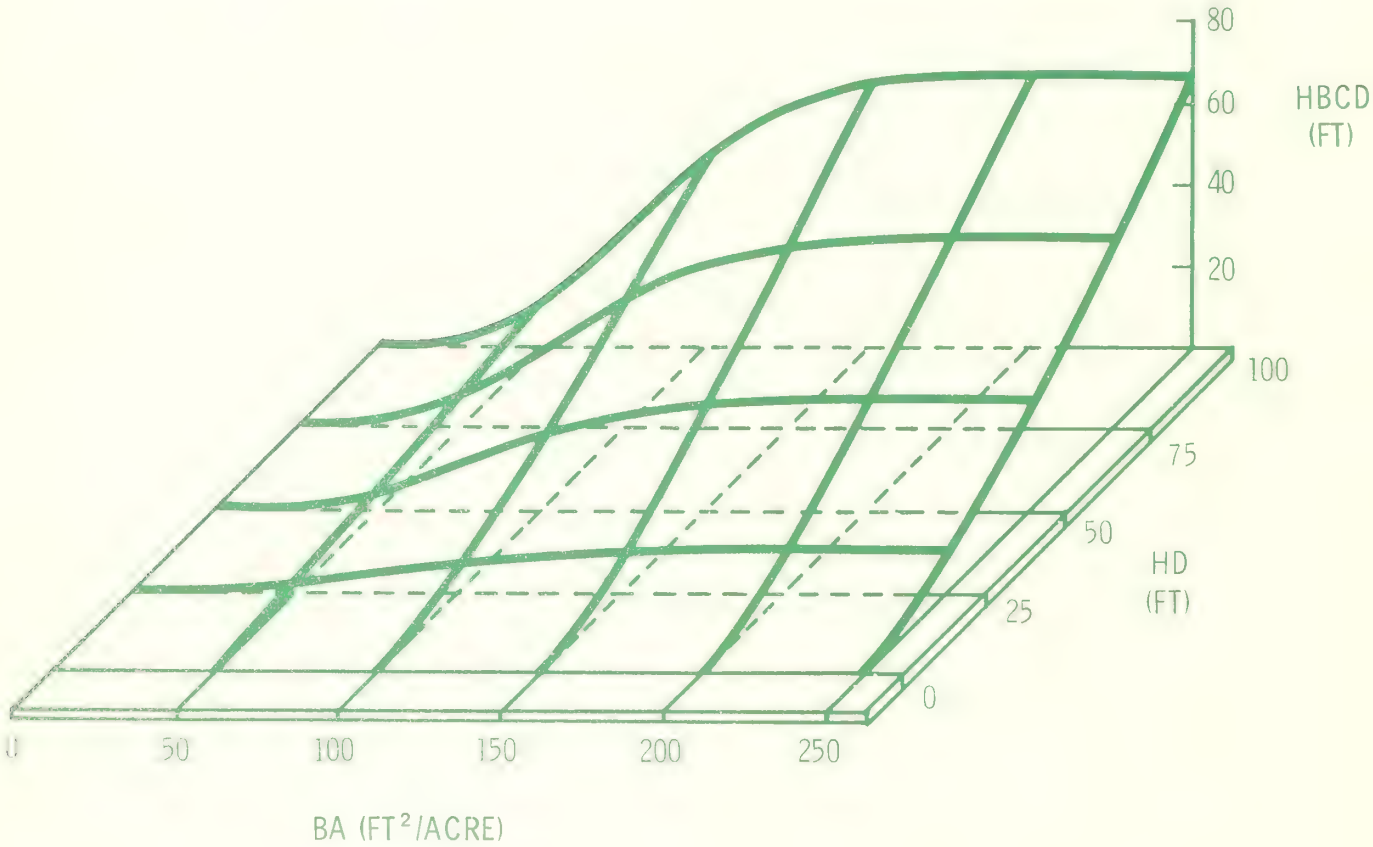


Figure 4.—Height to base of crown (HBCD) as a function of basal area per acre (BA) and average height of dominant trees (HD).

Table 1.—Height to base of crown (HBCD) in feet as a function o[illegible] trees (HD) in feet[1]

HD	BA 25	50	75	100	125
10	0	0	[illegible]	[illegible]	[illegible]
20	0	1	3	5	[illegible]
30	0	2	6	[illegible]	[illegible]
[illegible]	[illegible]	3	8	[illegible]	[illegible]
[illegible]	[illegible]	4	11	18	23
60	[illegible]	[illegible]	14	23	[illegible]
70	[illegible]	[illegible]	[illegible]	28	[illegible]
[illegible]	[illegible]	8	[illegible]	34	[illegible]
[illegible]	[illegible]	9	[illegible]	40	[illegible]
100	2	10	[illegible]	45	[illegible]

[1]Value [illegible]

Crown Competition Model

Like BA, the CCF-effect on HBCD was e[illegible] positive and sigmoidal while the effect of h[illegible] again expected to be positive and nearly lin[illegible] n = 134) were again separated into 10-ft (3[illegible] groups and HBCD was plotted over CCF wi[illegible] height group (fig. 5).

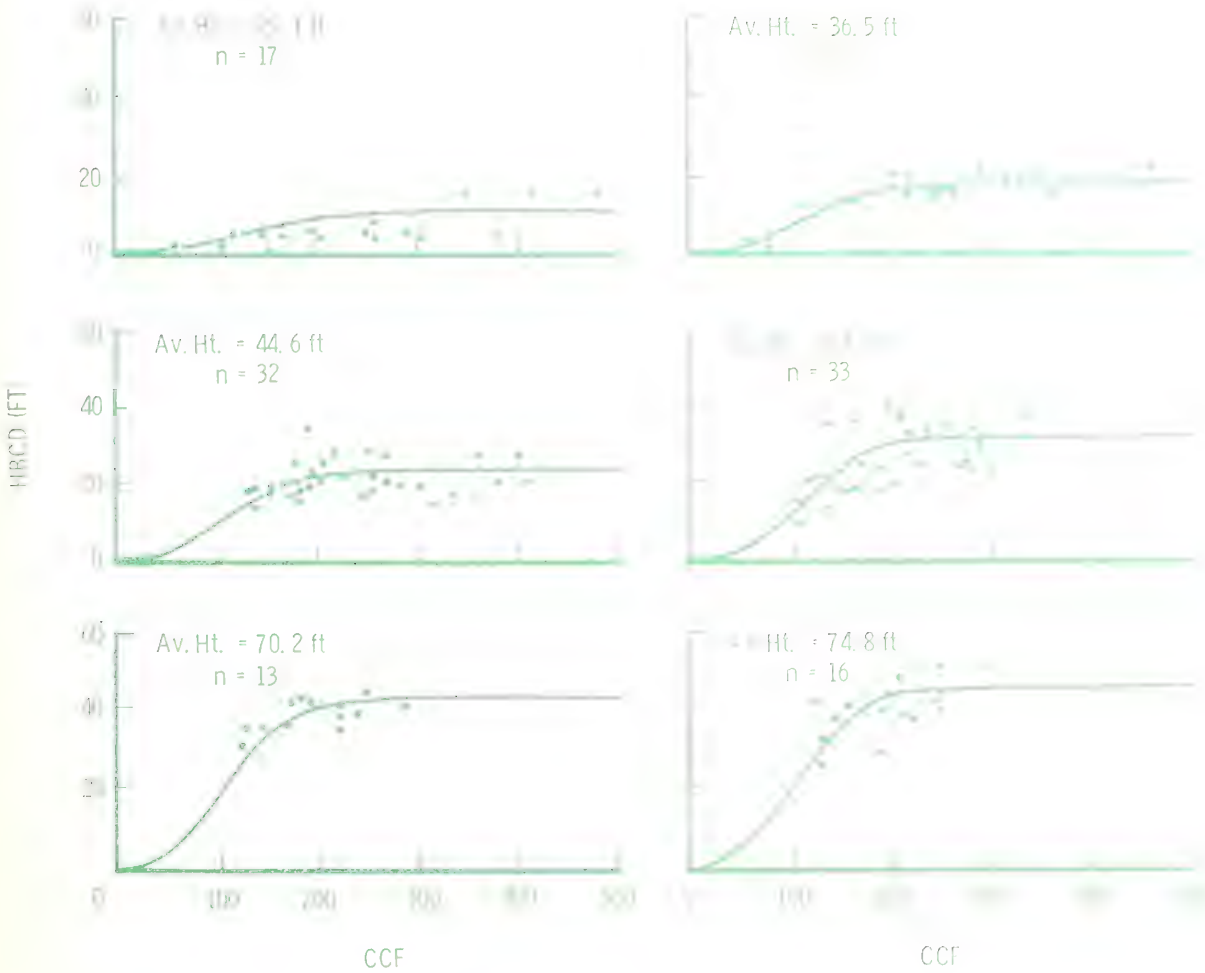


Figure 5.—Sigmoidal effect of CCF on HBCD, by tree height g[illegible]

The expected sigmoidal CCF-effect was clearly visible in the data and appeared to break downward from the asymptotes at about the same point in CCF (180-200) at all heights. As with BA, the strongest expression of the sigmoidal form appeared to exist in the 30- to 50-ft (9.1- to 15.3-m) HD groups. Following Jensen and Homeyer (1970), these sigmoids were well estimated by e^{-K} with n = 10, and $0.183 \leq I \leq 0.190$. Since the range in "I" was slight, I = 0.186 was finally adopted as a compromise for all curves; thus the relationship of HBCD to CCF over the entire range of HD was expressed by a single sigmoidal form.[3]

The maximum heights of the HBCD - CCF sigmoids occurred at CCF-500, which represented the upper limit of model application in CCF. Subsequent to plotting and smoothing the changing maximum heights of the sigmoids over HD, this parameter, called YP_{CCF}, was described after the methods of Jensen and Homeyer (1971) by a slightly concave-upward curve (fig. 6). Its mathematical expression is: $YP_{CCF} = 0.12056\,(HD)^{1.37}$.

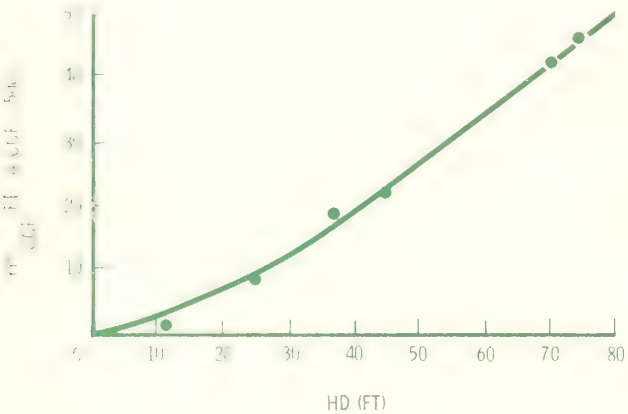


Figure 6.—Maximum heights (YP_{CCF}) in feet of HBCD over CCF sigmoids for the means of 10-foot dominant height classes.

The complete hypothesis is specified as:

$$[2] \qquad HBCD = (YP_{CCF}) * e^{-\left|\frac{\frac{CCF}{500} - 1}{0.814}\right|^{10}} * 1.0498^{4/}$$

where: $\overline{HBCD} = 23.3$ ft, $R^2 = 0.85$, and $s_{y \cdot x} \simeq 4.7$ and limits are: $0 \leq CCF < 500$: and $0 \leq HD < 100$.

The model is represented as a response surface in figure 7, and estimated values generated from the model for representative levels of CCF and HD are presented in table 2.

[3] The unscaled sigmoidal form for HBCD was:

$$\left|\frac{CCF}{500} - 1\right|^{10}$$

$$1 - 0.186$$

[4] Least squares scaling coefficient (b_i) — in this case the value 1.0498 was obtained by fitting the hypothesized relation to the data from which it was partially derived (see section on "Scaling Models to Local Conditions" for determination of b_i for other data sets).

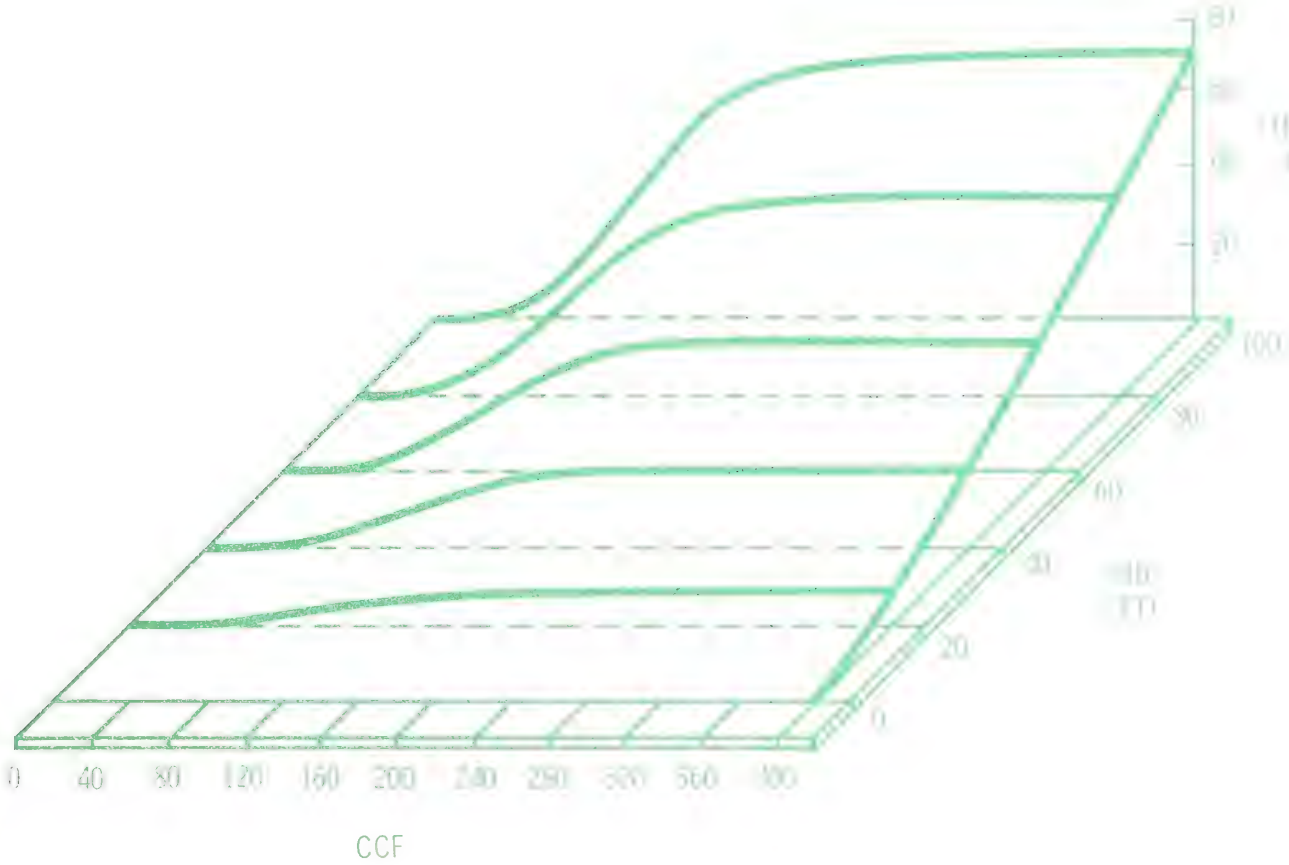


Figure 7.—Height to base of crown (HBCD), as a function of crown competition factor (CCF) and average height of dominant trees (HD).

Table 2.—Average height to base of crown (HBCD) in feet for dominant trees, as a function of crown competition factor (CCF) and average height of dominant trees (HD) in feet[1]

	CCF										
HD	40	60	80	100	120	140	160	180	200	300	500
10	—	—	1	1	2	2	3				
20	—	1	2	3	5	6	6	7	7	[illegible]	
30	—	2	3	6	8	10		12		13	13
40	1	2	5	9	12			18		20	20
50	1	3	7	12	16	20	23	25	26	27	27
60	1	[illegible]	9	15	[illegible]	26	[illegible]	32			35
70	1	[illegible]	11	18	26	[illegible]	[illegible]	39		43	
80	2	6	13	22	[illegible]	38	43	47	49		
90	2	7	[illegible]	26	36	45	51	55	57	60	60
100	2	8	[illegible]	30	[illegible]	[illegible]	59	64	66	69	

[1] Values within the block fall within the range of the basic data

Scaling Models to Local Conditions

The models (equations [1] and [2]) can be adjusted to data sets from other populations of lodgepole pine trees through a simple least squares fitting of model estimates to observed sample values of HBCD (forcing the regression through the origin) to obtain a least squares scaling coefficient (b_i) for each population: $b_i = \Sigma XY / \Sigma X^2$, where X = estimated HBCD, according to equation [1] or [2], and Y = actual HBCD from the pertinent data set.

The value of the coefficient (b_i) is used to scale estimates from equations [1] or [2] to local conditions as shown in equation [3]:

$$[3] \qquad HBCD_i = HBCD * b_i.$$

Equations [1] and [2] with [3] provide estimates of the average position (height above ground) of dominant tree crowns in natural even-aged lodgepole pine stands, as a function of their stand density and average height of dominant trees. Average depth (length) of dominant tree crowns can be estimated for a stand, following estimation of HBCD, as the difference between the average height of dominant trees (HD) and HBCD. Although the position and depth of the dominant crown class does not indicate the total depth and position of the stand canopy, we believe the dominant parameters can serve as effective statistical indicators of various biological relationships associated with crown characteristics of the overall stand.

Overall Position and Depth of Stand Canopies

To provide further insight into the overall depth and position of lodgepole pine stand canopies, we examined the relationship between average height to the base of crowns of suppressed trees (HBCS) and HBCD, for a 27-stand subsample of the 134 stands used to develop the HBCD models. We found that HBCS in feet can be estimated with the relationship:

$$[4] \qquad HBCS = -4.19 + 0.39\ HBCD + 0.18\ HD$$

$$R^2 = 0.84$$

Therefore, equation [4] can be used subsequent to estimating HBCD, to estimate HBCS — thereby providing an estimate of the position of the overall canopy in relation to height in feet above the ground. Overall estimated depth of the canopy can be calculated as the difference between HD and HBCS for the stand.

Forecasting of Future Characteristics of Lodgepole Pine Canopies

To obtain estimates of the canopy position and depth of a stand at various later ages, reliable estimates of HD and BA or CCF must be possible for those future ages. Realistic values of these parameters can be obtained with computerized tree and stand growth projections for lodgepole pine (Stage 1973; Myers and others 1971; Edminster 1978). The models reported in this paper can also be embedded in such computer programs to provide vertical crown development information in addition to the other stand development information they provide. In embedding the crown models in computer growth projection programs, it is important that stand density reductions (due to invoking thinning subroutines) do not cause crowns to "grow-back-down-the-bole." We prevented this by defaulting the value of HBCD following thinning at any period, to the value calculated from the crown model (equations [1] or [2]) just prior to the thinning. We did this with a stand projection program for lodgepole pine (Myers and others 1971), modified to include growth equations developed from Montana and Idaho stand data (Cole 1971; Cole and Stage 1972; Stage 1975). We found that equations [1] and [2] gave similar results under natural stand development; however, when low thinnings were simulated, equation [2] gave less realistic results. We believe this might be due to the change in tree numbers and their diameter distribution being inconsistent with the regression coefficients of the CCF equation for lodgepole pine (Alexander and others 1967). This equation was developed from unmanaged stand data and relates total crown coverage of natural stands to the number and size of open grown trees necessary to obtain 100 percent crown coverage. Basal area, on the other hand, can be accurately calculated regardless of changes in the diameter distribution of the stand, because of its direct mathematical relationship to number and diameters of trees.

Because the CCF values are influenced by thinning (particularly by repeated low thinnings that systematically skew-upward the diameter distribution), we recommend that only equation [1], the crown model involving basal area as the stand density measure, be used to preview crown development under thinning and other managed-stand scenarios.

An example of the results using equation [1] to preview yield and other effects is summarized in table 3 for stand densities of 2,000 and 8,000 trees/acre (4 940 and 19 760/ha), and for no-thinning contrasted with both a single precommercial thinning and precommercial thinning with subsequent commercial thinnings.

Table 3 indicates that, among other effects, heights and crown lengths (canopy depth) are increased over time by repeated thinnings when compared to no-thinning. However, height to crown (canopy position) is also elevated by repeated thinnings, in comparison to no-thinning, because the removal of suppressed trees in low thinnings removes this portion of the overall canopy. Repeated computer trials of this kind can reveal a favorable (if not optimum) management regime for attaining or maintaining specified values of these important stand parameters during stand development.

3.—Stand development u

19 760 ha) in lodgepole pine or

Age	Manage-ment status[1]	No. trees/ acre	stand diameter	Basal area	Domi-	Domi-nant
	N	2,000		63		
	P	473		2		
		473				
	N	1,525				
	P	458	6.1			
	C	332	6			
		1,163	5.0			
	P	415				
	C	227				28
	N	888		169		
		358	8.7			
	C	157	10.8			
	N					
		298	9.7			
		142	12.2			
	N	8,000		20		
	P	539				
	C	539	2.3	16		
	N	5,664		8		
	P	523	5			
		349	6.2			
	N	3,281		195		
		472				
	C	239				
	N	1,998	4.2			
	P	403	8.3			
	C	163	10.6			
140		1,324		188		
		332				
		147	12.0			

[1]Management statu

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Cole, Dennis M.; Jensen, Chester E. Models for describing vertical crown development of lodgepole pine stands. Res. Pap. INT-292. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 10 p.

Interaction models are presented for describing height and depth of crowns, of the dominant crown class of lodgepole pine stands as a function of total stand height and either basal area or crown competition factor. A regression model is also presented to provide estimates of total canopy depth and position. Suggestions are made for using the models in computer simulations; and an example given of how vertical crown parameters change in relation to other stand parameters, under different management situations.

KEYWORDS: crown models, crown development, canopy depth, canopy position, lodgepole pine

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A Calibration Model for Screen-caged Peltier Thermocouple Psychrometers

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RESEARCH SUMMARY

Calibration is one of the most important steps in using thermocouple psychrometers for estimating water potential. Unfortunately, the calibration process has numerous problems, including: (1) the logistics of calibrating large numbers of psychrometers; (2) applying isothermal calibration data to unstable thermal environments; (3) projecting limited calibration data to extended ranges of temperature and water potential; and (4) visually interpolating and extrapolating data from hand-drawn curves. A mathematical model of psychrometer calibration was developed that should alleviate most of these problems and enhance calibration accuracy. The model applies to a water potential range of 0 to about -80 bars, a temperature range of 0° to 40° C (32° to 104° F) and to Peltier cooling times of from 15 to 60 sec. In addition, the model includes a correction for the effects of temperature gradients on psychrometer performance as reflected by zero-offsets ranging from -60 to +60 microvolts. Within the limits established, this model is applicable to screen-caged psychrometers constructed with 0.0025-cm (0.001-inch) diameter chromel-constantan thermocouples that employ a Peltier cooling current of 5 ma. Techniques of psychrometer calibration and cleaning are discussed together with the details of the model, its application, and limitations.

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INTRODUCTION

Thermocouple psychrometers are useful instruments for measuring the water potential of soils, plant tissues, and other media in the laboratory and the field. Unfortunately, they must be carefully calibrated under elaborately controlled conditions to insure accurate data. The calibration process involves establishing the relationship between microvolt output and known water potentials over a range of temperatures. These relationships are usually represented, for each psychrometer, as sets of hand-drawn curves that form the basis for estimating water potential from known microvolt and temperature data. However, calibration is time consuming, expensive, and subject to multiple errors when many psychrometers are used.

Calibration errors are commonly associated with using improper techniques, applying laboratory data to unstable thermal environments, and interpolating data from hand-drawn curves. Because the reliability and accuracy of a thermocouple psychrometer are defined by the quality of its calibration, it is essential that one use proper techniques tempered with stringent adherence to detail and procedure (Brown 1970; Meyn and White 1972; Rawlins 1966; Slavik 1974; Wiebe and others 1971). In addition, it is usually recommended that each psychrometer be calibrated individually because common methods of construction often result in some variability among units that may affect their calibration characteristics (Wiebe and others 1971). However, in recent years the field use of thermocouple psychrometers in large numbers has become a common research method. This seriously complicates the logistical procedures of calibration when attempting to include the entire range of variables likely to be encountered under field conditions for dozens, or perhaps hundreds, of psychrometers.

Serious problems arise when attempting to relate laboratory calibrations made under isothermal conditions to field data collected in unstable thermal environments. Although the errors caused by temperature gradients have long been recognized (Rawlins and Dalton 1967), the normal practice has been to ignore them. Not until Wiebe and others (1977) and Wiebe and Brown (1979) quantified the errors caused by temperature gradients could suggestions be made of how to avoid them, or otherwise minimize their effects. They defined the magnitudes of temperature gradient errors and identified various flaws in psychrometer design that aggravate them. Michel (1979) subsequently studied temperature gradient effects on psychrometer calibration over narrow ranges of microvolts and temperatures.

Four primary variables can be identified as influencing estimates of water potential with thermocouple psychrometers: (1) the microvolt output of the psychrometer; (2) the equilibrium temperature of the sample and the psychrometer; (3) the Peltier cooling current and length of cooling time; and (4) the influence of temperature gradients on psychrometer output. Although psychrometers may differ slightly in their calibration characteristics, generally they all have highly predictable responses to these variables within certain limits (Brown 1970; Meyn and White 1972; Michel 1979; Rawlins 1966; Wiebe and others 1971). Also, calibration characteristics of psychrometers remain rather stable if the thermocouple is kept clean and its geometric position remains unaltered. For example, Brown and Johnston (1976) found that calibration outputs of psychrometers changed only 1.2 percent after 40 months of continuous field exposure.

This strong predictability of response to the four primary variables, together with the long-term stability of calibration characteristics, suggests that mathematical modeling may be useful in circumventing some of the problems associated with psychrometer calibration. A model would provide the interactive form and internal scales for the relations involved, and would express the average performance of the population of psychrometers used in its development. Also, a model would ideally be

applicable to psychrometers of other populations that are constructed with similar materials and techniques. Gross adjustment of the model using a small number of well-controlled calibration measurements would suffice to make the model applicable to any new psychrometer or group of psychrometers. The limits of accuracy would be established by the range of variability among the psychrometers, and could be predicted by model verification. If these limits are acceptable, the model could prove to be highly useful for establishing the calibration characteristics of large numbers of psychrometers with a minimum of time, expense, and possible error due to interpretation of hand-fitted and drawn relationships. Further, using the assumption that the unique characteristics of each psychrometer can be identified with only one or a few calibration points, their responses over the entire range of the four primary variables could be predicted within prescribed limits of error using the model. Estimates of water potential with from one to any number of psychrometers could then be automated by computer programing methods. Although at first glance it may appear that some level of accuracy may be sacrificed by this method, most errors associated with manual data manipulation would be eliminated.

The potential value of psychrometer calibration modeling has long been recognized (Rawlins 1972; Van Haveren and Brown 1972). Unfortunately, only the efforts of Meyn and White (1972) have been documented in detail. Their model was based on the performance of only eight psychrometers, and related microvolt output to a narrow range of water potentials (0 to about -46 bars) over a restricted temperature span, 8° to 25° C (46.4° to 77° F). In addition, their model was valid for only one Peltier cooling time under isothermal conditions. Michel (1979) attempted to predict the effects of temperature gradients on psychrometer estimates of water potential, but only studied narrow ranges of these two variables between 20° and 30° C (68° to 86° F).

The model developed here is designed to predict estimated potentials over the range of environmental conditions most likely to be encountered in the field. Generally, the model predicts water potentials over the range of sensitivity of chromel-constantan Peltier psychrometers, or from 0 to about -80 bars. Also, it applies to an ambient temperature range of 0° to 40° C (32° to 104° F) for Peltier cooling times of 15 to 60 sec, and for temperature gradient conditions that create about ±1° C (±1.8° F) temperature difference between the sensing and reference junctions of the psychrometer (zero-offset of ±60 microvolts). In addition, the predictive model was used to evaluate the following hypotheses:

1. The microvolt response of any given psychrometer (of similar design criteria to those used here) to water potential, temperature, Peltier cooling time, and temperature gradients can be modeled and predicted to within at least the limits of error normally expected with hand-drawn calibration curves.

2. The normal limits of error encountered in calibration can be reduced by adjusting the model over the range of appropriate variables as a function of a few calibration points for any individual psychrometer of similar design.

3. The time and expense normally devoted to hand calibration can be significantly reduced by modeling calibration.

4. Large quantities of either field or laboratory data can be analyzed more quickly and with fewer errors using the model-concept than with conventional methods.

Recent technology advances in electronic instruments permit the use of such a model in microprocessor circuitry with field-operated meters and data storage and retrieval systems. This capacity can significantly reduce the amount of data processing required, and permits nearly instantaneous evaluation of data outputs.

REVIEW OF THEORY CONCEPTS

The development of a model for thermocouple psychrometer calibration depends, in part, upon an understanding of the basic concepts of these instruments. In addition, it is essential to recognize the role of the different variables that affect the performance of psychrometers.

Thermocouple Psychrometers

The theory of how thermocouple psychrometers operate has been described in detail (Spanner 1951; Rawlins 1966; Dalton and Rawlins 1968; Peck 1968, 1969; Brown 1970; Wiebe and others 1971; Brown and Van Haveren 1972; Scotter 1972; and Slavik 1974). Basically, psychrometers are used to infer the water potential of soils, plant tissues, and other media from measurements of equilibrium vapor pressure. Instruments have been designed for use in closed systems within a sealed chamber and for *in situ* use in the field.

Although a variety of design features have been developed, all Peltier thermocouple psychrometers now used have the same basic ingredients. They consist of a thermocouple constructed of 0.00254 - cm (0.001-inch) diameter chromel and constantan wires welded to form a sensing junction. A short distance back from the sensing junction these wires are each attached to separate copper lead wires of large diameter, forming the reference junctions of the psychrometer. The sensing junction and two reference junctions form the essential constituents of a thermocouple psychrometer.

The primary differences among types of psychrometers are the design and material used to construct the protective housing around the thermocouple. Usually the choice of material and the design of the housing are determined by the intended use of the psychrometer, although there are some exceptions. Materials used include ceramic, stainless steel screen, and solid stainless steel or Teflon tubing with a screen end window. The various advantages and disadvantages of these have been discussed (Wiebe and Brown 1979; Wiebe and others 1971; Wiebe, Brown, and Barker 1977; Brown and Van Haveren 1972; Brown 1970).

Measurements of Water Potential

Prior to measuring water potential, the psychrometer is suspended in a closed system containing soil, plant tissue, or other media. Vapor pressure equilibrium is reached when the water potential of the medium and the vapor pressure of the air around it are in dynamic equilibrium. Under isothermal conditions the temperatures of the medium, the air, and the psychrometer are all equal.

When these conditions are achieved, water potential measurements are made using the Peltier effect. A small electrical current (about 5 ma) is passed through the psychrometer circuit from the constantan to the chromel side of the thermocouple for a brief time (usually about 15 sec). This current causes the sensing junction to cool slightly below ambient temperature (the maximum efficiency of chromel-constantan thermocouples is about 0.6° C [1.08° F] below ambient temperature). If the thermocouple is cooled below the dew-point of the atmosphere surrounding it, water vapor in the air will condense on the sensing junction. Following a specified cooling time the current is terminated, and the condensed water on the junction immediately begins to evaporate back into the surrounding atmosphere. During this phase the thermocouple is again cooled, but now as a function of the rate of evaporation, which is a function of the vapor pressure of the atmosphere and hence of the water potential of the medium. In this manner the Peltier effect allows a thermocouple psychrometer to be used as a wet-and-dry bulb instrument.

If the atmosphere adjacent to the thermocouple is at the saturated vapor pressure, the ambient temperature and the dew-point temperature will be identical, and thus water will not evaporate from the sensing junction. This situation corresponds to saturation or a 0 bar water potential, and will be detected as a 0 microvolt output on the meter. However, if a vapor pressure deficit exists in the surrounding atmosphere, evaporative cooling of the wet sensing junction will occur at a rate directly related to the magnitude of the deficit. This corresponds to a drier situation than saturation, and will be detected as a microvolt output from the thermocouple. Thus, the drier the water potential of the medium, the greater will be the microvolt output from the psychrometer. If the water potential is drier than about -85 bars, however, the dew-point temperature will likely be more than 0.6° C (1.08° F) below the ambient temperature. At this point and beyond, the efficiency of the Peltier effect is no longer great enough to condense sufficient water on the sensing junction to achieve stable readings. This represents the approximate lower limit of sensitivity for chromel-constantan thermocouple psychrometers.

General Calibration Procedures

Thermocouple psychrometers can be calibrated by suspending the instrument in a sealed chamber containing a water vapor source of known water potential at a constant temperature (Barrs 1968; Brown 1970; Brown and Van Haveren 1972; Campbell 1972; Meyn and White 1972; Rawlins 1966, 1972; Slavik 1974; Wiebe and others 1971). Normally an electrolyte solution such as NaCl or KCl of known molality is used as a vapor source. The relationship between water potential and solution concentration at various temperatures is available from standard tables (Lang 1967; Wiebe and others 1971; Brown and Van Haveren 1972)

A piece of filter paper saturated with the solution is sealed with the psychrometer in the chamber. Calibration is usually performed in a water bath under isothermal conditions because both psychrometer output and water potential are temperature-dependent variables. Psychrometer outputs in microvolts are then plotted against water potential in bars for several different temperatures to yield a family of curves. Since the relationship between psychrometer output and water potential is not linear throughout the entire range, several different salt solutions are used for each of several temperatures.

The importance of careful and precise calibration technique has been stressed (Rawlins and Dalton 1967; Brown 1970; Wiebe and others 1971; Meyn and White 1972). Everything known about psychrometer responses is based on calibration. Electrolyte solutions must be prepared with great care, and all materials used including the psychrometers, chambers, filter paper, and other accessories must be thoroughly and rigorously cleaned. In addition, care must be exercised in maintaining precise temperature control to minimize the effects of temperature gradients and to accurately establish the relationship between psychrometer output and temperature.

The Role of Temperature Gradients

Temperature gradients are a natural phenomenon (Wiebe and others 1977). Although thermocouple psychrometers are designed and calibrated for use under isothermal conditions, *in situ* applications in the field invariably lead to problems associated with temperature gradients. Thermal instability in a system leads to, among other phenomena, the movement of water vapor from warmer to cooler regions. Essentially, temperature gradients cause errors in estimates of water potential by disrupting the thermal stability between the sensing junction of the psychrometer and the evaporating sample surface, or between the sensing and reference junctions (Rawlins and Dalton 1967; Wiebe and others 1977; Wiebe and Brown 1979; Michel 1979).

Wiebe and Brown (1979) analyzed differences in temperature between the sample and the psychrometer and showed that temperature gradients may cause several types of errors: (1) if the average sample surface and the sensing junction temperatures differ, their vapor pressures will be identical but their relative vapor pressures will differ; (2) water may condense at, or evaporate from, the surface being measured by the psychrometer depending upon the direction of heat movement; and (3) water may become trapped within solid chambers consisting of "end-window" type designs. They concluded

that these errors can be minimized with proper psychrometer design criteria: (1) concentric geometry with the sensing junction located in the middle or toward the distal end of a cylindrical or spherical sample surface; (2) use of single-junction thermocouples that permit detection of thermal gradients; (3) use of materials with low heat conductivity; and (4) miniaturization of components consistent with stability, ruggedness, and ease of construction.

Among the commercially available designs that currently meet these criteria are the ceramic cup and screen-caged units of Wescor and the stainless steel screen-caged units of J. R. D. Merrill. Although these units minimize errors due to temperature differences that may occur between the psychrometer and the sample, such errors may still occur.

The null-output in microvolts of a psychrometer under true isothermal conditions prior to Peltier cooling will be zero. This indicates that the net microvoltage outputs of both the reference and the sensing junctions counterbalance each other, a phenomenon referred to as the Seebeck effect (Van Haveren and Brown 1972). However, when a temperature gradient exists within the psychrometer (the temperatures of the reference junctions and sensing junctions are not equal), the null-output will either be positive or negative depending upon the direction of heat movement. This null-output in microvolts has been termed the "zero-offset" (for instance, the microvolts of offset from zero) by Wiebe and others (1977), Wiebe and Brown (1979), and Michel (1979) and is used to detect the presence and magnitude of temperature gradients.

The output generated by chromel-constantan thermocouples is about 60 microvolts per degree (33.3 microvolts per degree Fahrenheit) in the temperature range of 0° to 70° C (32° to 104° F) (Omega Engineering, Inc. 1976). Thus, an offset from zero of +60 microvolts would indicate that the sensing junction was about 1° C (1.8° F) cooler than the reference junctions, and conversely, a -60 microvolt offset indicates the sensing junction is 1° C (1.8° F) warmer. Although the precise magnitude of a temperature gradient may not always be known, its relative magnitude and direction can be calculated by knowing the offset from zero (Michel 1979) and the distance between the sensing and reference junctions. Generally, positive offsets result in water potential estimates that are too dry (microvolt outputs are too high), whereas negative offsets yield readings that are too wet (microvolt outputs are too low).

METHODS AND PROCEDURES

The influences of the four primary variables on psychrometer performance incorporated in the model were investigated using two different calibration procedures. Isothermal calibration was used to determine the effects on psychrometer output of (1) water potential, (2) equilibrium temperature, and (3) Peltier cooling time. The fourth variable, temperature gradients, was assessed by nonisothermal calibration methods.

Isothermal Calibration

The methods of isothermal calibration used in this study follow the general procedures discussed above with a few modifications. A total of 24 screen-caged single-junction thermocouple psychrometers (fig. 1) were used that had been selected at random from a total population of 270 units (Brown and Collins 1980). These units are identical to those constructed by various commercial companies (J. R. D. Merrill, EMCO, and Wescor) in all respects affecting psychrometers operation and function. Some unique design features were added, which have since been adopted by these companies, but they do not affect the basic characteristics of chromel-constantan instruments. Therefore, it is anticipated that the data collected in this study are representative of similar screen-caged psychrometers employing a protective housing that provides a 360° evaporative surface concentric to the sample surface.

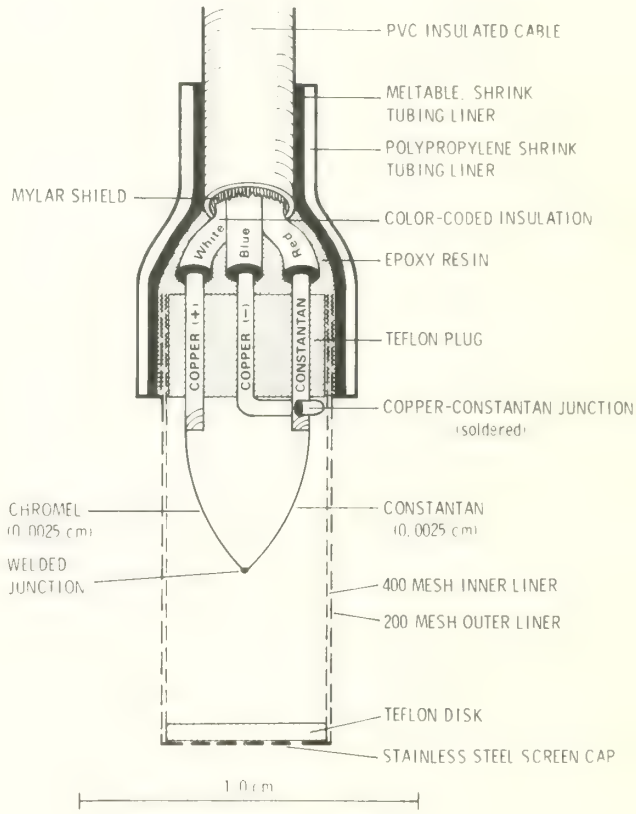

Figure 1.—Screen-caged single-junction Peltier thermocouple psychrometer used to develop the calibration model (after Brown and Collins 1980).

The same 24 psychrometers were used throughout this phase of the study. Each psychrometer was sealed in a stainless steel chamber identical to those described by Brown and Collins (1980) and illustrated in figure 2. With the lower cap removed, the entire sidewall of the chamber around the psychrometer was lined with a Whatman No. 1 filter paper strip previously cut to size. The filter paper was then saturated with a NaCl solution dispensed from a drop-bottle, with the excess poured off and discarded. Then the lower cap was immediately replaced over the chamber and sealed.

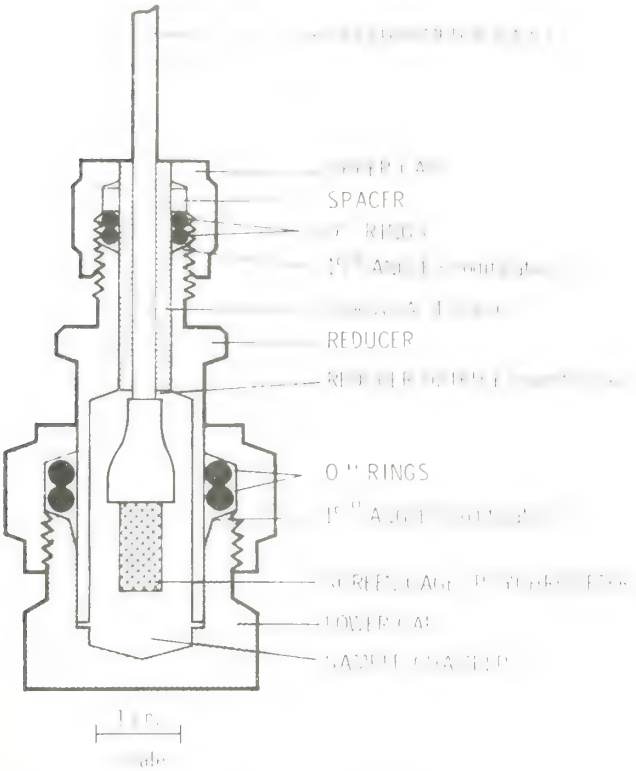

Figure 2.—Stainless steel calibration chamber with sealed psychrometer in place (after Brown and Collins 1980).

A summary of the NaCl molalities and temperatures used in this study appears in table 1, together with the water potentials of the solutions. Each solution was prepared separately with reagent grade NaCl (see Brown and Van Haveren 1972, pages 302-308 for detailed procedures). The 0 molality solution consisted of distilled-deionized water.

A Forma Scientific refrigerated water bath (model 2324) was used to maintain constant temperature control within limits of ±0.01° C (0.018° F). We used a modified top on the bath that provided a rubber seal around both the lead wires of the psychrometers and the rim of the reservoir to reduce the effects of evaporative cooling on bath temperature. The temperature stability within the bath was monitored regularly using four separate measuring systems: (1) two National Bureau of Standards calibrated mercury-in-glass thermometers to the nearest 0.01° C (0.018° F); (2) a thermistor and electronic digital thermometer; (3) a differential copper-constantan thermocouple with a 5-cm (2-inch) span between junctions; and (4) the copper-constantan thermocouple circuit in each of the 24 psychrometers. The bath demonstrated excellent stability at all temperatures under continuous use, and the differential thermocouple never indicated a greater temperature difference than 0.0025° C (0.0045° F) between its junctions.

Table 1.—Summary of water potentials in bars for NaCl molalities and temperatures used in calibration (after Lang 1967)

NaCl molality	Temperature				
	0° C	7.5° C	15° C	25° C	35° C
	Water potential, bars				
0	0.0	0.0	0.0	0.0	0.0
0.2	-8.36	-8.60	-8.84	-9.15	-9.46
0.5	-20.70	-21.36	-22.00	-22.81	-23.62
0.7	-29.01	-29.98	-30.91	-32.10	-33.28
1.0	-41.69	-43.18	-44.59	-46.40	-48.15
1.5	-63.59	-66.06	-68.37	-71.34	-74.11
1.7	-72.60	-75.50	-78.20	-81.70	-84.90
1.8	-77.30	-80.35	-83.30	-87.00	-90.40
1.9	-81.90	-85.30	-88.40	-92.40	-96.00
2.0	-86.70	-90.25	-93.60	-97.80	-101.60

After the 24 psychrometers were sealed within their chambers they were immersed in the bath. About a 35-cm (14-inch) section of lead wire above the calibration chamber was also submerged into the circulating water to reduce the effects of heat conduction along the wires. Temperature equilibration between the water bath and the chambers was usually achieved within 30 min, but vapor pressure equilibrium within the chambers usually required from 2 to 6 hours. Temperature equilibrium was detected as a 0 microvolt offset on the microvoltmeter (Wiebe and others 1977; Wiebe and Brown 1979), and vapor pressure equilibrium was assumed when two reproducible water potential outputs were read 1 hour apart. The 0 (distilled-deionized water) and 0.2 molal solutions required longer equilibration times, whereas the more concentrated solutions required shorter times. Also, in general, vapor pressure equilibration was slower at cool temperatures and faster at warm temperatures.

In an effort to reduce variability, all 24 psychrometers were calibrated simultaneously with the same solution. The microvolt outputs of each psychrometer were measured with an SB-Systems 600 meter to the nearest 0.1 μV, and temperature was recorded to the nearest 0.1° C (0.18° F). Questionable readings were checked only

after 30 min reequilibration time. The psychrometer outputs were recorded beginning with the 0° C (32° F) temperature first, and then followed successively with each next higher temperature up to 35° C (95° F). We found it convenient to immerse the set of psychrometers in the 0° C (32° F) bath late in the afternoon and allow them to equilibrate overnight. After the readings were recorded the next morning, the bath temperature was reset at 7.5° C (45.5° F). The data at this temperature were then recorded when vapor pressure equilibrium had been reached, and the process was repeated for each successive temperature. Using this procedure, from 3 to 5 days were required to collect the calibration data for each solution.

Chances of water vapor condensation within the chambers were reduced somewhat by sequentially increasing the temperature after each set of readings. However, the first set of readings of 0° C (32° F) may have been affected by water condensation, which would in part explain the much longer equilibration process at this temperature. Once condensate forms within the chamber, reevaporation of the liquid drops and the establishment of vapor pressure equilibration are severely slowed.

All psychrometers and calibration chamber components were thoroughly cleaned and dried each time the NaCl solutions were changed. Each component was sprayed with electronic tuner cleaner (LPS Instant Cleaner, LPS Research Labs., Inc., Los Angeles, CA 90025) to remove grease and other contaminants. Then all components were washed vigorously with distilled-deionized water. A squeeze-bottle with a narrow-neck spout was used to force water into the screen-cage of the psychrometers to remove all traces of tuner cleaner, salt solution, or other contaminants. The components were blown dry with filtered compressed air at 60 psi, and then completely dried at 80° C (176° F) in a forced-draft oven overnight. After the components had cooled to room temperature, maintained between 20° and 25° C (68° to 77° F) the rubber o-ring seals were treated with a thin coat of Dow Corning silicone grease to facilitate proper sealing and movement of parts, and then reassembled.

With the lead wires connected to the meter, psychrometer outputs in microvolts as a function of water potential and temperature were measured with Peltier cooling times of 15, 30, and 60 sec. For our psychrometers we used the optimum Peltier cooling current, which had been previously determined to be 5 ma. Generally the optimum current for chromel-constantan thermocouples of this type is between 3.5 and 5 ma (Merrill and Rawlins 1972). In this manner, data were assembled for inclusion in the model to describe the influence of the first three primary variables on psychrometer performance.

Nonisothermal Calibration

The objective of this phase of the study was to assess the effects of temperature gradients on psychrometer response to known potential and temperature conditions. Six psychrometers of the original 24 were randomly selected and imbedded in a sand column saturated with one of the NaCl solutions. We originally had attempted to use nine psychrometers, but the logistics of the technique proved to be too complex to permit accurate assessment of each instrument in unstable thermal environments. The sand column was contained in a plexiglass tube 11.4 cm in diameter by 35.6 cm length (4.5 inches by 14 inches) fitted with sealable stainless steel plates at both ends

The sand used in the column was a No. 3 grit that had been washed to remove salts and other foreign matter and then dried. The sand was presaturated with an NaCl solution and then allowed to drain while in a sealed plastic bag to reduce evaporation. This moistened sand was lightly packed in the plexiglass tube until it was nearly half full, and then the psychrometers were positioned half way between the two end plates of the column and perpendicular to them. Three of the psychrometers were placed with their sensing junctions facing up and the other three facing down (180 degrees in the other direciton, but parallel to each other). Opposing placement of the psychrometers provided nearly equal, but opposite zero-offsets, when a temperature gradient passed through the system. The psychrometers were positioned about 1 cm (0.39 inch) apart, and moist sand was lightly packed around them to hold them in place. A 30-cm (12-inch) section of lead wire of each psychrometer was coiled at the same location, but away from the zone of immediate influence on the psychrometers, to minimize the effects of heat conduction along the wires. The remainder of the tube was then filled, but care was taken to pack the sand lightly around the psychrometers to insure intimate contact with them. The lead wires of the psychrometers extended up through the sand column and exited the plexiglass tube near the top. The top plate was sealed in place with self-tapping screws, and RTV silicone rubber was used to insure a watertight seal.

The entire tube was submerged in the water bath and allowed to reach temperature and vapor pressure equilibrium. Usually about 3 hours were required to reach temperature equilibrium within the large mass of sand, but between 24 and 48 hours were required to achieve vapor pressure equilibrium. Under these conditions, the zero-offset was first verified at 0 microvolts, and then the water potential and temperature data were recorded. These data served to verify psychrometer consistency between the isothermal and nonisothermal calibration methods. In virtually all cases the same outputs were recorded for given water potentials and temperatures in both experiments. The same NaCl solutions (up to 1.5 m NaCl), temperature range, and Peltier cooling times were used in both the isothermal and nonisothermal experiments.

To achieve nonisothermal conditions around the psychrometers, the sand column was elevated to different levels part way out of the water bath. It was found that, with care, the thermal stability in the sand column could be disrupted and a new temperature gradient induced while maintaining a fairly stable ambient temperature around the psychrometers. The difference in temperature between the water bath and the laboratory room was thus used as the source of temperature gradients in the sand column. By adjusting the level of the column in the water, and by tilting it to various angles, virtually any magnitude of temperature gradient could be achieved. With these kinds of manipulations, reasonably constant temperature gradients could be induced, as indicated by the zero-offset output from the psychrometers. Both positive and negative zero-offsets of large magnitude were easily achieved. As discussed by Michel (1979), positive zero-offsets were generally indicated when the sensing junction was cooler than the reference junctions, and negative offsets when the sensing junction was warmer than the reference junctions, which is the reverse of how Wiebe and others (1977) reported their zero-offset observations.

Wiebe and others (1977) explained that the magnitude of the zero-offset only provides an estimate of the magnitude of temperature gradients. They showed that calculated values of temperature gradients based on the thermocouple thermal constant (60 microvolts per degree) and the dimensions of the thermocouple can vary slightly from measured temperature gradients. They suggested that the sensing and reference junctions likely respond to the "average" temperature of the psychrometer cavity. This explanation is quite plausible since the two reference junctions may be at different temperatures while the sensing junction may be at yet another temperature. Thus, the direction of heat movement within the psychrometer cavity can influence the magnitude of the zero-offset microvoltage with virtually infinite variations.

Therefore, we did not measure the actual temperature gradients within the sand column with separate thermocouples since such data are of little or no value for developing a predictive model, and since the opportunity to do so under field conditions is rarely available (except where two or more psychrometers are stacked in the soil). Rather, we relied on the assumption that, for given water potentials and ambient temperatures, each level of zero-offset would yield an error of consistent magnitude. Our preliminary studies to verify this, together with the final analyses of the data, showed that the assumption was correct. However, of even greater importance is the fact that zero-offsets and associated estimates of water potential could be repeatedly reproduced for each set of temperature and NaCl molality conditions. Michel (1979) similarly found that zero-offsets affect water potentials in a predictable manner, and concluded that they can be used to correct the estimates of water potential made under thermal gradients. Our data and experience suggest that zero-offsets alone are of little value as direct measures of temperature gradients, as originally suggested by Wiebe and others (1977), but are essential for adjusting microvolt outputs to correct estimates of water potential directly affected by the temperature gradient.

An attempt was made to allow the system to achieve a stable thermal gradient before data were collected, but the time required to reach stability varied with different temperature conditions. Usually an hour or more was required to achieve stable temperature gradients for each new position of the sand column in the water bath. When a desired level of temperature gradient (or, more correctly, zero-offset) was reached, the zero-offset, water potential estimate in microvolts, and the ambient temperature for each psychrometer were recorded. Prior field experience suggested that most observed zero-offsets commonly occur within the range of about -60 to +60 microvolts. These extremes of zero-offset were therefore selected as the limits for the predictive model, although occasional field observations may stray well beyond these limits.

RESULTS AND DISCUSSION

Psychrometer Responses

The psychrometer calibration data collected under isothermal conditions are summarized in table 2 and figure 3 a, b, and c. Generally these data show that the 24 psychrometers used here display the same calibration characteristics as those of different design and manufacture (Brown 1970; Meyn and White 1972; Wiebe and others 1971). The mean microvolt outputs increase with longer Peltier cooling times and with increasing temperatures. Outputs increase from 0 microvolt at 0 molality (0 bar water potential) to a maximum near 1.8 molal (about -75 to -90 bars, depending upon temperature), and then decrease sharply beyond this point. Thermocouple psychrometers with similar design features as those used here are most sensitive in the range of 0 to about -80 bars, and sensitivity increases with temperature. At water potentials drier than about -80 bars their sensitivity declines rapidly, and the variability among psychrometers increases substantially. Beyond the region of maximum microvolt output, the variability among psychrometers is so great that it is of little or no predictive interest. Therefore, only the water potential region of maximum sensitivity (0 to about -80 bars) was included in the predictive calibration model. The 1.9 and 2.0 molal data in table 2 are only included here to illustrate the rapid decline in psychrometer output at these dry water potentials.

It is interesting to note the low microvolt outputs for the 0 molal (0 bar) solution. Other workers have frequently reported small positive outputs of about 0.2 to 0.5 microvolt at 0 bar water potential, presumably due to water absorption on chamber walls or heating of the reference junctions during Peltier cooling (Meyn and White 1972; Wiebe and others 1971). We found that the theoretical output of 0 microvolt could be achieved routinely if we adhered to scrupulous cleaning procedures and long equilibration times of 15 to 20 hours.

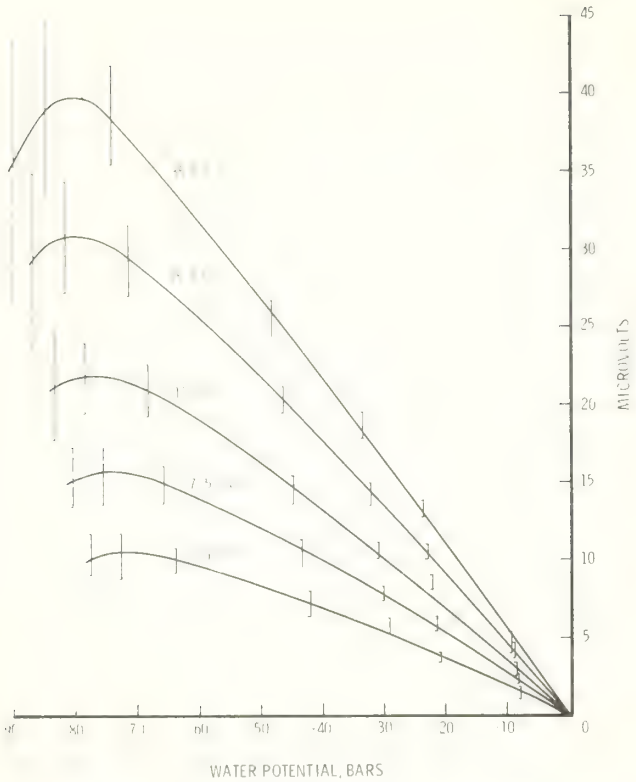

Figure 3a.—Calibration curves for isothermal conditions with 15-sec cool time. Standard deviation shown for each set of data.

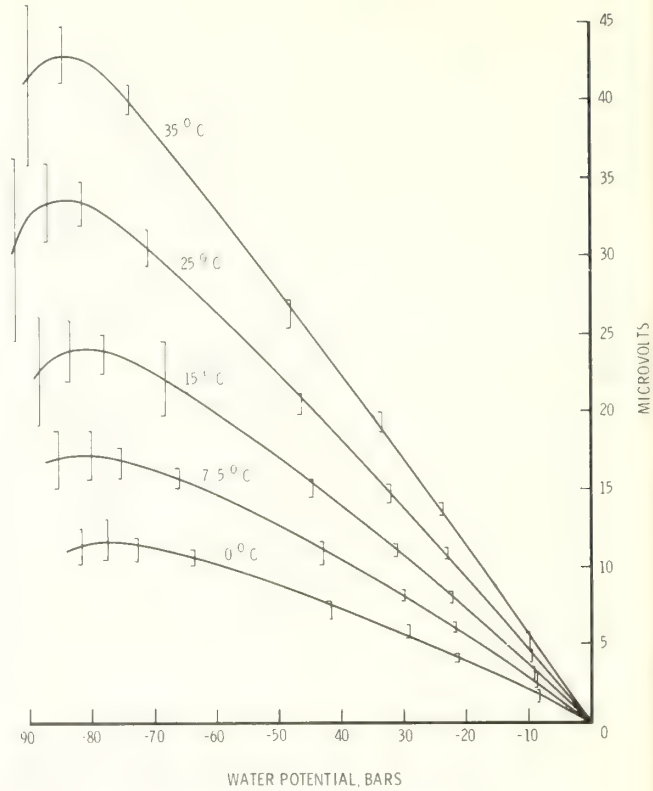

Figure 3b.—Calibration curves for isothermal conditions with 30-sec cool time. Standard deviation shown for each set of data.

Table 2.—Summary of isothermal calibration data for each NaCl molality, temperature (°C), and Peltier cooling time (seconds). Values shown are in microvolts. The upper value in each row is the mean ($\bar{x}$) for the 24 psychrometers, and the lower value is the standard deviation (sd)

NaCl molality		Temperature and cooling time (seconds)														
		0 °C			7.5 °C			15 °C			25 °C			35 °C		
		15	30	60	15	30	60	15	30	60	15	30	60	15	30	60
0	($\bar{x}$)	0.00	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10
	(sd)	.00	.00	.00	.00	.00	.10	.00	.00	.10	.00	.00	.10	.00	.00	.10
0.2	($\bar{x}$)	1.38	1.64	1.82	2.26	2.47	2.61	2.87	3.05	3.28	4.02	4.15	4.47	4.75	5.04	5.33
	(sd)	.40	.38	.37	.41	.40	.37	.44	.40	.40	.58	.48	.45	.73	.54	.50
0.5	($\bar{x}$)	3.71	3.95	4.17	5.97	6.10	6.41	7.65	7.95	8.27	10.51	10.79	11.12	13.25	13.68	14.03
	(sd)	.30	.24	.24	.35	.30	.27	.39	.31	.21	.45	.35	.26	.46	.35	.22
0.7	($\bar{x}$)	5.63	5.75	5.85	7.78	8.12	8.40	10.62	11.02	11.33	14.23	14.64	15.04	18.71	19.34	19.73
	(sd)	.41	.40	.42	.47	.35	.31	.52	.38	.30	.73	.55	.44	.63	.57	.41
1.0	($\bar{x}$)	7.04	7.21	7.55	10.32	10.67	11.10	14.46	14.92	15.35	20.35	20.88	21.62	25.97	26.16	27.23
	(sd)	.70	.60	.53	.96	.65	.48	.93	.59	.48	.96	.65	.56	.91	.90	.52
1.5	($\bar{x}$)	9.91	10.45	10.96	14.82	15.51	16.14	20.91	22.04	22.30	29.37	30.42	31.33	38.68	39.95	40.79
	(sd)	.70	.61	.53	.96	.81	.75	1.12	2.39	.92	1.45	1.20	1.17	1.20	.98	.97
1.7	($\bar{x}$)	10.16	11.11	11.81	15.38	16.60	17.50	21.73	23.68	24.81	30.80	33.37	34.94	39.30	42.91	44.94
	(sd)	.77	.78	.74	1.20	1.04	.92	1.69	1.30	1.08	2.30	1.43	1.25	3.23	1.83	1.35
1.8	($\bar{x}$)	10.39	11.56	12.63	15.30	17.13	18.50	21.27	23.88	25.46	29.17	33.40	35.73	34.98	40.93	44.96
	(sd)	1.54	1.27	1.05	1.99	1.62	1.34	2.51	1.87	1.41	3.72	2.62	1.76	5.79	5.20	3.64
1.9	($\bar{x}$)	9.52	11.17	12.40	14.45	16.78	18.32	18.96	22.45	24.93	25.29	30.29	33.89	28.67	35.57	40.45
	(sd)	1.33	1.18	.95	1.91	1.85	1.80	3.56	3.63	3.31	5.63	5.96	5.76	8.56	9.90	10.44
2.0	($\bar{x}$)	7.26	9.34	10.75	10.81	12.97	15.76	14.19	17.53	20.40	16.00	19.80	23.16	17.78	20.60	24.62
	(sd)	2.51	2.46	2.66	3.77	4.32	4.71	6.22	6.85	7.31	9.86	11.36	12.47	13.32	14.97	16.54

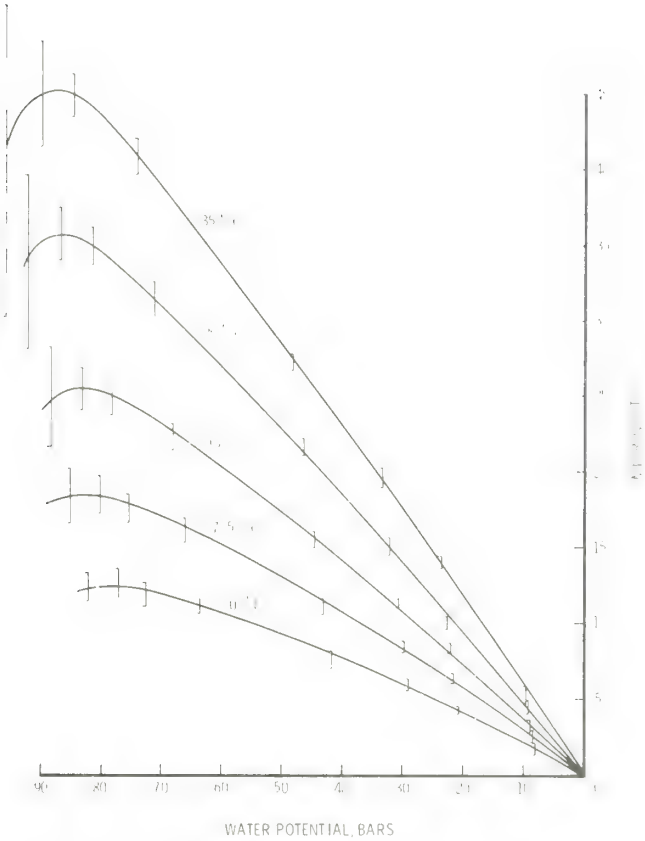

Figure 3c.—Calibration curves for isothermal conditions with 60-sec cool time. Standard deviation shown for each set of data.

The standard deviations (sd) in table 2, and illustrated in figure 3, indicate both the variability among the 24 psychrometers and the ranges of water potentials and temperatures over which they display their greatest consistency. Generally the psychrometers were most variable at the extreme water potentials and at the cooler temperatures studied. However, in most cases the standard deviations were 10 percent or less of the mean outputs at water potentials ranging from about -10 to -80 bars throughout the temperature range studied. Also, longer Peltier cooling times resulted in less variability.

The relationships between psychrometer output and zero-offset obtained from nonisothermal calibration were established for each temperature regime, NaCl solution (up to 1.5 m), and Peltier cool time. An example of one such relationship for the six psychrometers used is illustrated in figure 4 for 25° C (77° F) at 0.5 m NaCl using 15-sec Peltier cool time. As was typical for all such relationships, the outputs of the six psychrometers used in the nonisothermal calibration at an offset of 0 microvolts were within the limits of ±1 sd of the mean output of all 24 psychrometers calibrated under the same conditions shown in table 2. The example in figure 4 illustrates that under positive zero-offset conditions, psychrometer outputs tend to be higher than under isothermal conditions. But, under negative zero-offset conditions, outputs tend to be lower than those under isothermal conditions (Wiebe and others 1977; Michel 1979). This relationship is strongly linear for all conditions studied with r^2 values ranging between 0.82 and 0.99 (table 3). The intercepts (b), slopes (a), and r^2 values of the psychrometer output versus zero-offset relationship for other water potentials and temperatures at 15-sec cool time are shown in table 3. Similar data were also collected for the 30- and 60-sec

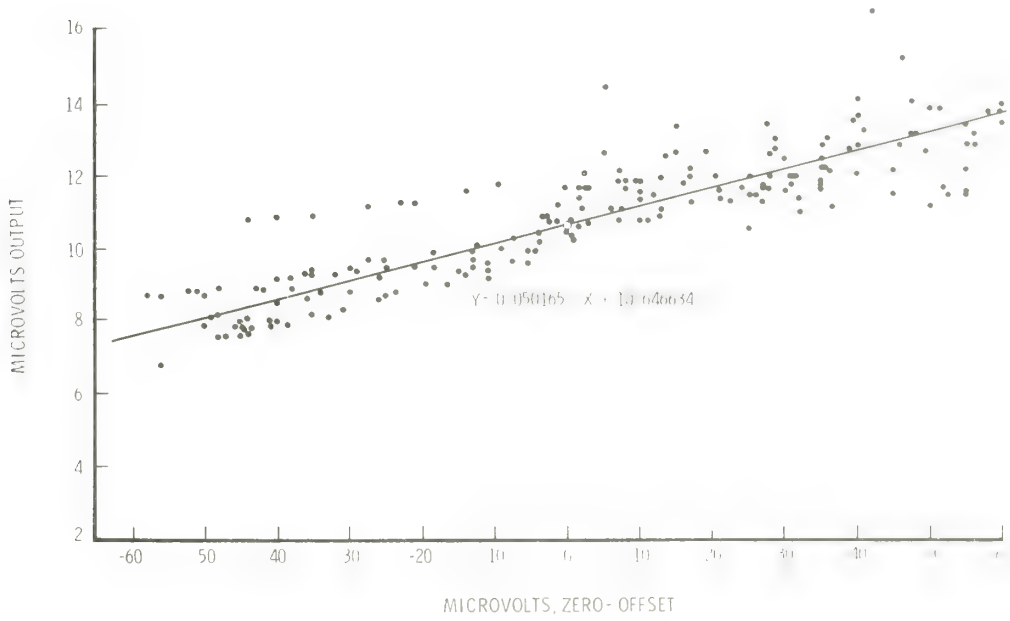

Figure 4.—Relationship between psychrometer output in microvolts and zero-offset at 25° C for 0.5 m NaCl solution and 15-sec cool time.

cool times, but the level of sampling was not as intensive.

The data in table 3 clearly show a strong effect of water potential on slope over the entire range of conditions sampled. Except at 0 bar water potential, the slopes increased with increasing temperature and decreasing water potential. Michel (1979) found this effect of temperature but found no effect of water potential. Michel (1979) studied narrower ranges of water potential (-5to-20 bars), temperatures (20° to 30° C [68° to 86° F]), and zero-offsets (-5 to +8 microvolts), and it is highly possible that the effects of water potential were masked by the variability among his observations. This leads to the conclusion that psychrometer output errors are the same at different water potentials. By selecting similarly narrow ranges within our own data (see fig. 4, between-5 and +8 microvolts of zero-offset), we were able to calculate slope values that resemble those presented by Michel (1979). It is apparent that a clearer and more accurate assessment of psychrometer response is possible when broader ranges of conditions are studied. As a result, his suggestion that each microvolt of zero-offset is accompanied by an error of 1.75 bars water potential, although accurate for his instruments, does not apply to psychrometers similar to those used here. It is now evident that a fixed level of error is not consistent with how screen-caged thermocouple psychrometers like those used in this study respond to these variables.

The magnitude of errors in psychrometer output caused by zero-offset (temperature gradients) is affected by both temperature and water potential. The effect of temperature is illustrated in figure 5, wherein the slopes of the curves relating output and zero-offset (table 3) were used to construct the relationship between psychrometer error and zero-offset. In this illustration, the data for the 0.5 m NaCl solution and the 15-sec cool time are displayed at temperatures ranging from 0° to 40° C (32° to 104° F). The y-axis represents the error in microvolts of psychrometer output for the range of zero-offsets and temperatures studied, and shows that psychrometer outputs are too high when positive zero-offset conditions

Table 3.—Intercepts (b), slopes (a), and r^2 values for psychrometer microvolt output vs. zero-offset for 15-second cool time

Temperature, °C		NaCl molal solution			
		0	0.5	1.0	1.5
0	b	0.018	3.944	7.191	9.884
	a	.011	.014	.029	.038
	r^2	.905	.899	.886	.884
7.5	b	.009	5.963	10.892	15.000
	a	.001	.029	.047	.065
	r^2	.891	.980	.887	.936
15	b	.101	7.919	14.865	20.717
	a	.010	.038	.069	.094
	r^2	.839	.893	.919	.989
25	b	.106	10.647	20.426	29.318
	a	.001	.050	.108	.141
	r^2	.950	.821	.862	.961
35	b	.100	13.441	26.195	38.208
	a	.013	.069	.133	.197
	r^2	.936	.896	.969	.897

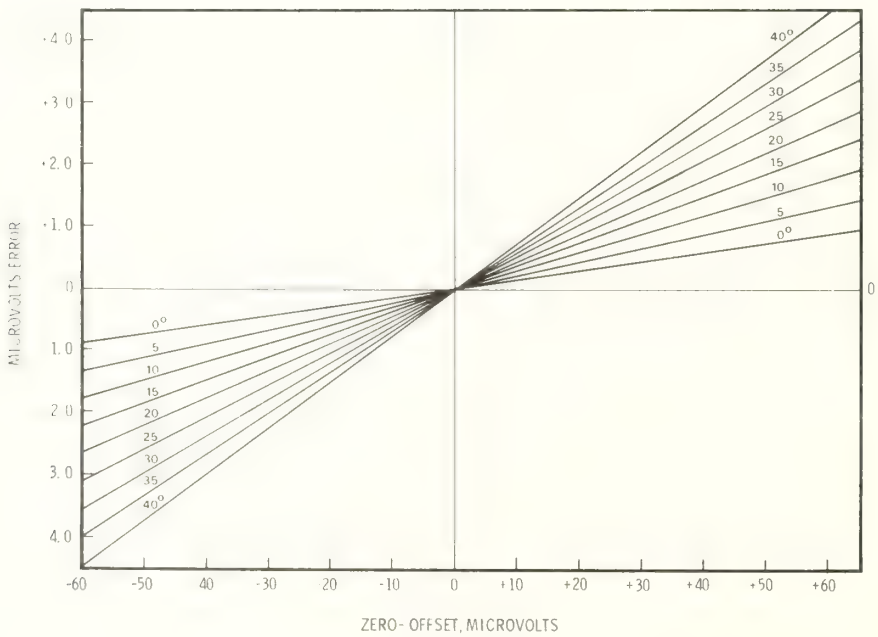

Figure 5.—Relationship between psychrometer error in microvolts and zero-offset for 0.5 m NaCl and 15-sec cool time for temperatures ranging between 0° and 40° C.

prevail, and are too low when negative zero-offset conditions prevail. Also, the size of the error is magnified as the temperature increases from 0° to 40° C (32° to 104° F), and as the zero-offset deviates further from 0 microvolts.

An example of the effect of temperature gradients (expressed as zero-offset) and water potential on psychrometer output is shown in table 4 for 25° C (77° F) and 15-sec cool time. The number of observations (n) shown for each zero-offset from 0 to ±60 microvolts represents only a small sample of all the observations made at other temperature gradients under these conditions. The mean psychrometer outputs in microvolts ($\bar{x}$) and their corresponding standard deviations (sd) illustrate, for this range of water potentials (0 to -71.3 bars), the general response and the range of variability that psychrometers display under temperature gradient conditions. Under isothermal conditions (0 zero-offset), the data are very similar to those shown in table 2 for the same conditions. Of considerable interest is the apparent lack of psychrometer response to temperature gradients at 0 bar water potential. This same effect was noted at the other temperature regimes studied, indicating that psychrometers are relatively insensitive to temperature gradients (between ±60 microvolts) under saturated conditions. Apparently vapor pressure differences within the psychrometer cavity are insufficient to cause a psychrometer response to temperature gradients under saturated conditions. However, as the water potential declines, psychrometer output progressively deviates from the expected isothermal output as zero-offset increases or decreases from 0 microvolt (the slope data in table 3 also show the same effect). The same basic relationships were also observed for all other temperatures and cooling times studied. The magnitudes of deviation in psychrometer output from isothermal calibration values tend to be greater at warmer temperatures and under longer Peltier cooling times, and are smaller at cooler temperatures and short cooling times.

The effect of temperature gradients (zero-offset) on psychrometer output is highly complex, and yet bears some rather subtle characteristics. Figure 6 illustrates the 0 to ±60 microvolt zero-offset data from table 4, and shows just how large an error zero-offset can cause in estimates of water potential with thermocouple

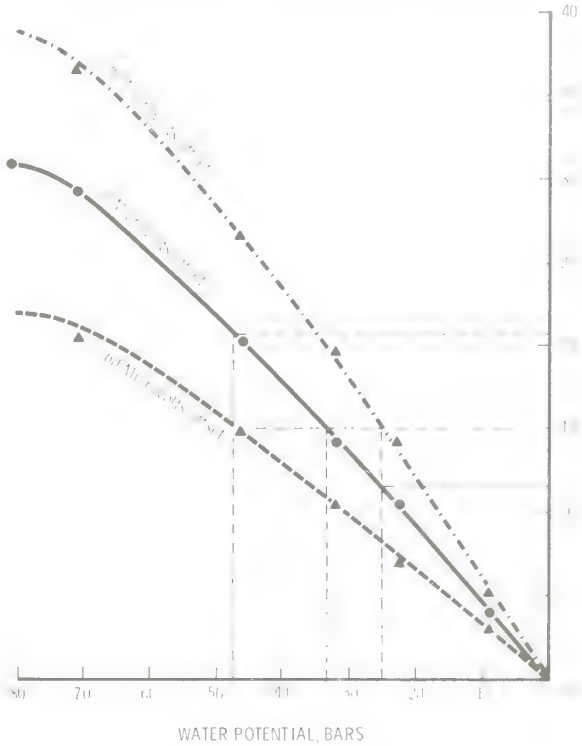

Figure 6.—Effect of zero-offset at +60, 0, and -60 microvolts on psychrometer output at 25° C and 15-sec cool time.

Table 4.—Effect of zero-offset and water potential on psychrometer output at 25°C with 15-second Peltier cool time. Number of observations (n), mean psychrometer output in microvolts ($\bar{x}$), and one standard deviation (sd) are shown

Zero-offset	Water potential, bars: 0 (0 m NaCl) n	$\bar{x}$	sd	−22.8 (0.5 m NaCl) n	$\bar{x}$	sd	−46.4 (1.0 m NaCl) n	$\bar{x}$	sd	−71.3 (1.5 m NaCl) n	$\bar{x}$	sd
0	21	0.1	0.1	20	10.4	0.3	20	20.5	0.5	15	29.2	0.5
−5	6	1	1	9	10.0	2	9	19.7	4	9	28.0	6
+5	6	1	1	9	10.6	1	9	20.9	4	9	29.3	6
−15	9	.2	1	6	9.8	3	6	18.3	.6	6	27.0	.7
+15	9	.1	1	6	11.4	3	6	21.5	.6	6	30.6	8
−30	9	1	1	6	8.8	4	6	17.1	5	8	24.7	1.3
+30	9	.1	1	6	11.9	6	6	23.5	.7	8	33.6	1.1
−60	10	2	1	15	6.9	5	12	14.9	.9	12	20.5	1.4
+60	10	.1	1	15	14.3	7	12	26.7	1.4	12	36.5	1.6

psychrometers. In its simplest form a reading of 15 microvolts under isothermal conditions (for the example in fig. 6) would indicate a water potential of about -33 bars. However, if a temperature gradient resulting in a zero-offset of +60 microvolts existed, the actual water potential for that reading would only be -25 bars. Had the zero-offset been ignored (which is a common practice), an error of 8 bars in the estimate would have resulted. On the other hand, if a -60 microvolt zero-offset occurred, the actual water potential would have been -47.5 bars, resulting in an error of about 14.5 bars if the correction were not made. The subtlety here is that for a given water potential, temperature, zero-offset, and cooling time, only one unique microvolt output is possible (within certain limits and assuming no condensation has occurred within the psychrometer). For instance, if the water potential was -25 bars in the example of figure 6, an output of 15 microvolts could only occur if a zero-offset of +60 microvolts also occurred simultaneously. Had there been no zero-offset (isothermal conditions), the psychrometer output could have only been about 11.5 microvolts (± some acceptable level of error). Conversely, if the medium was at -47.5 bars, the psychrometer output could only be about 20.6 microvolts if the offset was 0, or 15 microvolts if it was -60.

The progressively diverging zero-offset curves away from the isothermal calibration curve were not entirely anticipated. This relationship is particularly noticeable at the extreme zero-offsets such as those illustrated in figure 6. Of particular interest is the similarity of zero-offset curves to isothermal curves of other temperatures relative to 25° C (77° F). For example, the +60 and -60 microvolt zero-offset curves bear a striking similarity to the 35° and 15° C (95° and 59° F) temperature curves, respectively, shown in figure 3a. Although a comparison of their relative slopes (for instance, -0.284 at 15° C [59° F] and -0.289 and -60 microvolts, and -0.482 at 35° C [95° F] and -0.511 at +60 microvolts) shows they are not identical, their similarity suggests a possible relationship. Under a positive zero-offset, when the sensing junction is cooler than the reference junctions, psychrometer sensitivity (microvolts/bar) is enhanced somewhat as if temperature had been increased. But, under negative zero-offsets, sensitivity is depressed in a similar manner as if temperature had been decreased.

The validity of a predictive model for thermocouple psychrometers is based on the assumption that the relationships among temperature, water potential, cooling time, and temperature gradients are all reproducible for any given similar psychrometer, and that the variability among units is acceptably small. The data, such as those illustrated in figures 3, 4, 5, and 6, and those shown in tables 2, 3, and 4 appear to meet these criteria. Large numbers of observations made with numerous psychrometers, together with their relatively small standard deviations, indicate these relationships are all highly predictable.

The Predictive Model

The relationships between psychrometer outputs in microvolts and water potentials in bars form the basis of the predictive model. The data in table 2 and illustrated in figure 3a, b, and c, define the approximate limits of the isothermal portion of the model. Generally, the model is applicable within the temperature range of 0° to 40° C (32° to 104° F) for water potentials ranging from 0 to about -80 bars. The effects of both Peltier cooling time between 15 and 60 sec (for a 5-ma current), and zero-offset between -60 and +60 microvolts are also incorporated. Appropriate power functions and e-transforms were fitted to the data by least squares methods (Jensen and Homeyer 1970; 1971; Jensen 1973, 1976, 1979). The resulting model had an r^2 of 0.99 and performs acceptably throughout the required range of imposed conditions.

The overall modeling rationale was one of expressing microvolts (MV) as a calibrated function of water potential in bars (WP), temperature in degrees centigrade (Temp), and length of Peltier cooling time (Sec). The resulting function was then solved for WP, the final item of predictive interest.

For each of the 15 temperature and cooling time combinations, the curves of microvolts over water

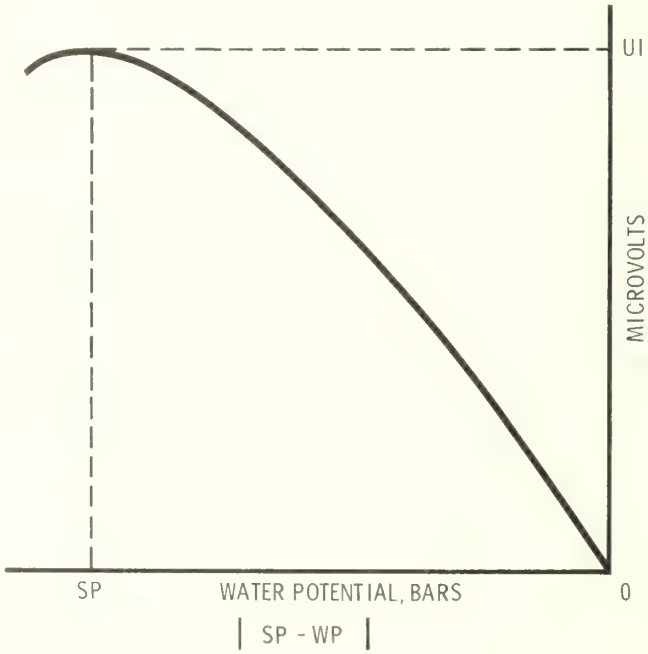

Figure 7.—Generalized relationship between microvolt output and water potential showing the relative positions of the curve peak (SP) and the scaled difference (UI) in microvolts at peak height.

potential were clearly defined by the array of observation means. All 15 trends were smoothed manually (fig. 3a, b, and c) and the entire relationship was described mathematically. Each curve over water potential was of the composite form: height of the peak (upper intercept, UI), minus a relatively flat power function ($1.18 \leq N \leq 1.36$) of the absolute difference between the point in water potential at which the curve peaked (SP) and some specified WP (for example, $|SP - WP|^N$) (fig. 7); scaled to the difference between UI and zero (= UI), for example $(UI/|SP|^N) * |SP - WP|^N$, or in total,

$$MV = UI - (UI/|SP|^N) * |SP - WP|^N \quad (1)$$

The inputs N, UI, and SP in equation 1 were found to vary over both temperature and time. For example, N varied sigmoidally over temperature (fig. 8) as follows:

$$N = 1.18 + 0.185 \left[\frac{e^{-\left|\frac{(40-Temp)}{40} - 1\right|^{M}} - e^{-\left(\frac{1}{1-I}\right)^{M}}}{1 - e^{-\left(\frac{1}{1-I}\right)^{M}}} \right] \quad (2)$$

where the inflection point (I) varied as a power function over time, so that

$$I = 0.45 + 0.000333(Sec) + (1.9846 \times 10^{-19}) * (Sec)^{10}, \quad (3)$$

and M varied as a sigmoid over time,

$$M = 2.5 + e^{-\left|\frac{\frac{(60-Sec)}{60} - 1}{0.405}\right|^{3.0}} \quad (4)$$

UI varied as a flat power function over temperature, such that

$$UI = INT_1 + 0.017288 * YP_1 * (Temp)^{1.1} \quad (5)$$

where INT_1 and YP_1 change over time;

$$INT_1 = 12.1 - 0.003475\,(60-Sec)^{1.63} \quad (6)$$

and

$$YP_1 = 39.2 - 0.0004346\,(60-Sec)^{2.45} \quad (7)$$

The point in the range of WP at which the curves peak (SP) varied as a flat power function of temperature, where

$$SP = INT_2 - YP_2 * 0.00017185\,(40-Temp)^{2.35} \quad (8)$$

where INT_2 and YP_2 changed over time so that;

$$INT_2 = 88 - 0.0002579\,(60-Sec)^{2.7} \quad (9)$$

and

$$YP_2 = 8.4 + 2.734 \times 10^{-7}\,(60-Sec)^{3.97} \quad (10)$$

The model to this point is applicable only under isothermal conditions. Where temperature gradients exist, microvolt readings are either increased or decreased from those with no gradient, depending upon the extent of the gradient and its direction. A measure of difference and direction is available in zero-offset microvolts (OMV), quantified in figure 5 as to its effect on the microvolt reading. Note that the effect changes with the average temperature of the medium. For convenience, this effect is called zero-offset error (ZOE) and is described mathematically from figure 5 as:

$$ZOE = 0.015\,(OMV) + 0.001471\,(TEMP)\,(OMV)$$

Correction of ZOE to that for cooling times other than 15 sec is provided by the ratio

$$(MVS/MV_{15}) * ZOE,$$

where MVS is the MV for whatever temperature and cooling time is specified, and MV_{15} is the MV at the same temperature and at the 15-sec cooling time. Both MVS and MV_{15} were collected at WP = -22.5 bars. A water potential of -22.5 bars is a compromise between the extremes of the entire water potential range studied, and represents the point at which the zero-offset effects were studied in the laboratory. Since the effects of zero-offset on psychrometer output are linearly related to changes in temperature, they are proportional at any water potential and temperature to an arbitrarily fixed point, here set at -22.5 bars.

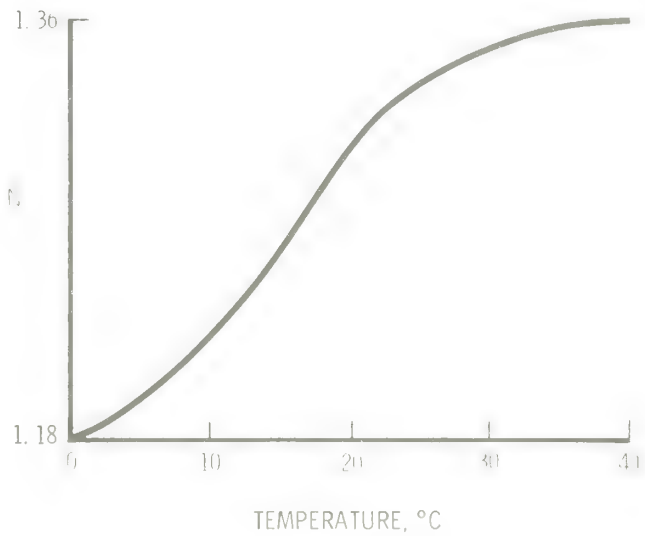

Figure 8.—Sigmoid relationship between N and temperature for 0° to 40° C.

The isothermal MV in equation 1 is then multiplied by the ratio 1/C to arrive at MV corrected for ZOE, where

$$C = \frac{MVS + \left(\frac{MVS}{MV_{15}}\right) * ZOE}{MVS} \tag{12}$$

and where C now provides a proportional correction to MV for any combination of WP, Temp, or Sec. Note that when ZOE is negative, C will be less than 1.0, and MV in MV/C becomes larger to compensate for the negative errors (fig. 5). When ZOE is positive, C will be greater than 1.0 and MV in MV/C becomes smaller to compensate the positive errors.

Finally, having multiplied the left side of equation 1 by 1/C to arrive at MV/C, we solved the resulting equation for observed microvolts (applicable under either isothermal or nonisothermal conditions),

$$MV = UI * C - \left(\frac{UI * C}{|SP|^N}\right) * |SP - WP|^N \tag{13}$$

where,

$$|SP - WP|^N = \frac{[(UI * C) - MV]}{\left(\frac{UI * C}{|SP|^N}\right)} \tag{14}$$

thus, the predicted water potential ($\widehat{WP}$) can be solved as

$$\widehat{WP} = \left\{\left[\frac{|SP|^N * ((UI * C) - MV)}{UI * C}\right]^{\frac{1}{N}} + SP\right\} * (-1) \tag{15}$$

within the limits $SP \leq \widehat{WP} \leq 0$.

The following parameters must be supplied to predict water potential with the model:

MV = microvolts psychrometer output,
OMV = zero-offset (-60 to +60 MV),
Temp = temperature (0° to 40° C), and
Sec = seconds cooling time (15 to 60 sec).

A program of the predictive model in FORTRAN and BASIC is presented in appendix I, together with a list of programing steps. We have successfully used the Monroe Model 1880, the Hewlett-Packard 9845B desk-top computer, and the Amdahl 470 V/6-II to predict water potentials over the entire range of the model. A limited computer printout of predicted water potentials is presented in appendix II for cooling times of 15, 30, and 60 seconds and for the temperature range of 0° to 40° C (32° to 104° F), with psychrometer output in microvolts for zero-offsets ranging from -60 to +60 microvolts.

The model is represented in three-dimensional form in figure 9 for the 60-sec cool time only. The relationships among the various factors are represented as surfaces for the extreme limits of zero-offset (from -60 to + 60 microvolts). Shorter cooling times would slightly lower the slopes of each surface, but the total effect is too small to illustrate effectively at the scale shown. This illustration shows the limits of the data in appendix II as well as the relative shapes of the surfaces for the conditions represented by the model.

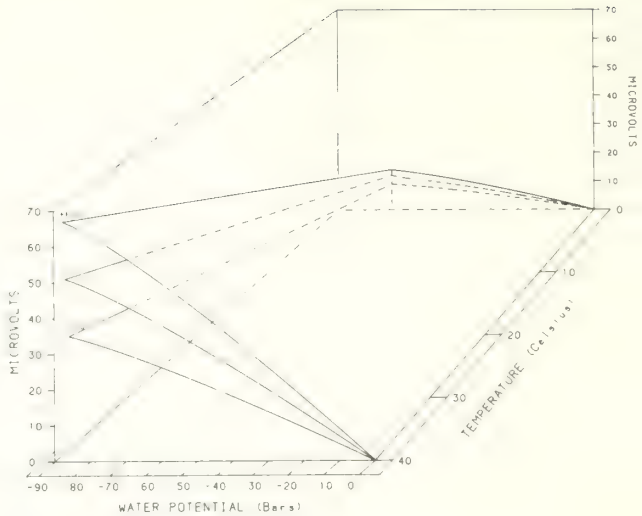

Figure 9.—Three-dimensional representation of model characteristics showing the relationships among water potential, microvolt output, temperature, and zero-offset for 60-sec cool time. Shorter cooling times are not shown because of their relatively small effect.

Model Verification

The general form and internal scales of the various relationships used in the model are presumed to apply to any individual or group of psychrometers similar to those used here. Uncorrected estimates of water potential by the model have been found quite reasonable, even for psychrometers not previously used. In fact, the isothermal portion of the model (under conditions of 0 zero-offset) appears to estimate water potentials quite adequately for virtually all designs of chromel-constantan psychrometers, including screen-caged, ceramic cup, and Teflon or stainless steel end-window types. However, the nonisothermal portions of the model (used when zero-offsets occur) may be more applicable for screen-caged units.

Nevertheless, the model contains some bias peculiar to the group of psychrometers used in its development, and to the process of hand-fitting the curves to the data points. It is expected that the predictability of the model would be strengthened if the bias were eliminated or reduced by employing a correction coefficient that would adjust for the unique characteristics of the specific psychrometer or group of psychrometers to be used in a

given application. A ratio of the actual water potential (or sum of actual water potentials where a group of psychrometers is used) to that estimated by the model provides a convenient correction coefficient. Thus,

$$B = \frac{\Sigma WP}{\Sigma \widehat{WP}} \tag{16}$$

where B is the correction coefficient, ΣWP is the sum of actual water potentials (of NaCl solutions used in calibration), and $\Sigma \widehat{WP}$ is the sum of estimated water potentials by the model for the microvolt outputs of the psychrometers being used. Model bias is then adjusted for that particular data set by

$$WP_{ad} = B \cdot \widehat{WP} \tag{17}$$

where WP_{adj} is the adjusted water potential in bars. When B = 1.0, the model estimate of water potential is identical to the actual value; but when B is less than 1.0, the model is estimating a drier water potential; and when B is greater than 1.0, it is estimating a wetter water potential. The adjustment is accomplished by multiplying the estimated water potential by B (equation 17).

Theoretically, psychrometers of uniform physical and chemical structure would all respond to water potentials and temperatures identically, and hence could be modeled more accurately. Unfortunately, psychrometers are not all identical; each has its own unique characteristics. Therefore, it is probably unrealistic to expect that the water potential of any psychrometer can be predicted with great accuracy throughout its entire range of sensitivity, regardless of the correction coefficient used. However, it is expected that model adjustments like those shown in equation 17, made either for each individual or for an entire group of psychrometers, will provide readily acceptable levels of accuracy (at least within the limits normally obtained from hand-drawn calibration curves).

The relative conformity of water potentials estimated by the model with those of the NaCl solutions (actual) used in calibration was assessed in two stages: (1) for the isothermal data of the original 24 psychrometers, and (2) for both the isothermal and nonisothermal data from a different set of psychrometers not previously used. The ability of the model to estimate water potentials from thermocouple psychrometer outputs over the ranges of temperature, zero-offset, and cool-time durations specified was determined.

Verification of the Isothermal Model

Comparisons of the actual and estimated water potentials under isothermal conditions over the temperature and water potential ranges studied are provided in table 5a, b, and c for the 15-, 30-, and 60-sec cool time durations, respectively. Actual water potentials are those of the NaCl solutions, and the estimated water potentials are those predicted by the model from the mean microvolt outputs shown in table 2. The adjusted estimates of water potential were calculated for each cooling time duration for all temperatures and NaCl solutions between 0.2 and 1.7 molal. The correction coefficient from equation 16 was calculated as the ratio of the sum of all actual water potentials to the sum of all estimated water potentials for each cooling time.

Separate correction coefficients (B values) could have been calculated for each NaCl solution and temperature, which would likely have reduced or eliminated the difference between the actual and adjusted estimates. However, this would be impractical for most applications since psychrometers are rarely used exclusively for a given set of water potential and temperature conditions. Under most situations it is not known beforehand what conditions a psychrometer will encounter; hence the correction coefficient for a specified cooling time duration is more practical.

The departures between the actual and estimated water potentials in table 5a, b, and c represent bias in the model (for example, variability among the 24 psychrometers used to develop the isothermal model, imprecise hand fitting of curves to the data, and any errors that may have occurred in calibration or other procedures). The adjusted estimate effectively reduces (and in some cases nearly eliminates) the departure from the actual water potential for the particular set of psychrometers used. However, a new adjusted estimate may be required for another group of instruments to minimize such departures. Had the data throughout the tables been calculated for any one psychrometer only, the departures between actual and adjusted estimates would have all been relatively small. Although model bias can be minimized substantially in some cases by adjusting the data for each individual psychrometer, it may be more practical to treat an entire population together in cases where large numbers of units are required. In such instances the departures between the actual and estimated water potential can be minimized by carefully selecting psychrometers with similar calibration characteristics.

The differences between the actual water potentials and those estimated by the model in table 5a, b, and c were entirely expected as a result of the hand-fitting procedures used. It is particularly reassuring, however, that the model estimates can be adjusted with such precision. The sums listed below of the actual, estimated, and adjusted estimates of water potential for each cooling time from the tables illustrate how equations 16 and 17 can be used to adjust the model output for a group of psychrometers.

	Table 5a (15 sec)	Table 5b (30 sec)	Table 5c (60 sec)
Σ actual	1270.56	1270.56	1270.56
Σ estimated	1236.23	1276.48	1284.11
Σ act. / Σ est.	1.02777	0.99536	0.9894[illegible]
Σ adj. est.	1270.50	1270.50	1270.54
Departure (Σ act. − Σ adj. est.)	0.06	0.06	0.02

The ratio of the sum of the actual to the sum of the estimated water potentials is the correction coefficient used to compute the adjusted estimated water potential for each cooling time. The departures between the actual and the adjusted estimates represent rounding-off errors in the computations. Note that the corrections required are relatively small; the largest is only 2.77 percent (for the 15-sec cool time)

ble 5a —Actual water potentials (bars) of NaCl solutions with 15-second cool time, estimated water potentials by the model, the adjusted-estimate of water potential, and the ratio of the actual to the adjusted-estimate for isothermal conditions

NaCl molality	Water potential	Temperature				
		0 °C	7.5 °C	15 °C	25 °C	35 °C
	actual	8.36	8.60	8.84	9.15	9.46
0.2	estimated	7.06	8.01	7.77	8.62	8.16
	adj. est.	7.26	8.26	7.99	8.92	8.39
	ratio	1.152	1.041	1.106	1.026	1.128
	actual	20.70	21.36	22.00	22.81	23.62
.5	estimated	19.68	21.99	21.38	23.04	23.21
	adj. est.	20.23	22.60	21.97	23.68	23.70
	ratio	1.023	.945	1.001	.963	.997
	actual	29.01	29.98	30.91	32.10	33.28
.7	estimated	31.00	29.30	30.38	31.68	33.26
	adj. est.	31.86	30.11	31.22	32.57	34.18
	ratio	.911	.996	.990	.986	.974
	actual	41.69	43.18	44.59	46.40	48.15
1.0	estimated	40.12	40.37	42.94	46.72	47.28
	adj. est.	41.24	41.99	44.74	47.85	47.44
	ratio	1.011	1.028	.997	.970	1.015
	actual	63.59	66.06	68.37	71.34	74.11
1.5	estimated	63.74	64.91	69.22	73.00	75.91
	adj. est.	65.51	66.71	72.79	74.66	78.02
	ratio	.971	.990	.939	.956	.950
	actual	72.60	75.50	78.20	81.70	84.90
1.7	estimated	—*	—*	—*	—*	—*
	adj. est.	—	—	—	—	—
	ratio	—	—	—	—	—

eyond the range of the model.

able 5b. —Actual water potentials (bars) of NaCl solutions with 30-second cool time, estimated water potentials by the model, the adjusted-estimate of water potential, and the ratio of the actual to the adjusted-estimate for isothermal conditions

NaCl molality	Water potential	Temperature				
		0 °C	7.5 °C	15 °C	25 °C	35 °C
	actual	8.36	8.60	8.84	9.15	9.46
0.2	estimated	8.41	8.71	8.19	8.68	8.44
	adj. est.	8.37	8.67	8.15	8.64	8.40
	ratio	0.999	.992	1.106	1.059	1.126
	actual	20.70	21.36	22.00	22.81	23.62
.5	estimated	20.96	22.25	21.98	23.06	23.33
	adj. est.	20.86	22.15	21.88	22.95	23.22
	ratio	.992	.964	1.005	.994	1.017
	actual	29.01	29.98	30.91	32.10	33.28
.7	estimated	31.49	30.28	31.13	31.74	33.44
	adj. est.	31.34	30.14	30.98	31.59	33.28
	ratio	.926	.995	.998	1.016	1.000
	actual	41.69	43.18	44.59	46.40	48.15
1.0	estimated	40.74	41.14	43.53	46.56	46.16
	adj. est.	40.55	40.95	43.33	46.34	45.94
	ratio	1.028	1.054	1.029	1.001	1.048
	actual	63.59	66.06	68.37	71.34	74.11
1.5	estimated	66.17	66.09	70.83	72.64	75.14
	adj. est.	65.86	65.78	70.50	72.30	74.79
	ratio	.966	1.004	.970	.987	.991
	actual	72.60	75.50	78.20	81.70	84.90
1.7	estimated	74.44	73.95	80.17	83.68	83.17
	adj. est.	74.09	73.60	79.79	83.29	82.78
	ratio	.980	1.026	.980	.981	1.026

Table 5c.—Actual water potentials (bars) of NaCl solutions with 60-second cool time, estimated water potentials by the model, the adju estimate of water potential, and the ratio of the actual to the adjusted-estimate for isothermal conditions.

NaCl molality	Water potential	Temperature				
		0 °C	7.5 °C	15 °C	25 °C	35 °C
	actual	8.36	8.60	8.84	9.15	9.46
0.2	estimated	8.96	8.97	8.83	9.32	8.72
	adj. est.	8.87	8.87	8.74	9.22	8.63
	ratio	.943	.969	1.011	992	1.096
	actual	20.70	21.36	22.00	22.81	23.63
.5	estimated	21.19	22.76	22.81	23.61	23.36
	adj. est.	20.97	22.52	22.57	23.36	23.11
	ratio	.987	.948	.975	.976	1.022
	actual	29.01	29.98	30.91	32.10	33.28
.7	estimated	30.54	30.42	31.79	32.32	33.27
	adj. est.	30.22	30.10	31.45	31.98	32.92
	ratio	.960	.996	.983	1.004	1.011
	actual	41.69	43.18	44.59	46.40	48.15
1.0	estimated	40.72	41.49	44.27	47.59	46.85
	adj. est.	40.29	41.54	43.80	47.09	46.35
	ratio	1.035	1.039	1.018	.985	1.039
	actual	63.59	66.06	68.37	71.34	74.11
1.5	estimated	65.50	65.93	69.00	72.80	74.16
	adj. est.	64.81	65.23	68.26	72.03	73.37
	ratio	981	1.013	1.002	.990	1.010
	actual	72.60	75.50	78.20	81.70	84.90
1.7	estimated	74.48	74.70	80.73	84.59	84.49
	adj. est.	73.69	73.91	79.87	83.69	83.59
	ratio	.985	1.022	.979	.976	1.016

In general, the data in table 5a, b, and c show that the greatest proportional bias in the isothermal model occurs at the highest water potentials (0.2 m NaCl) for all temperatures between 0° to 35° C (32° to 95° F). Other than at 0.2 m NaCl, there appears to be no consistent effect of water potential, or of temperature, on the difference between the actual and the adjusted estimate of water potential. The departure between these two quantities generally is less as cooling time duration increases from 15 sec to 60 sec, but the relationship is not always consistent for every set of conditions. However, these data do show that favorable adjustments of the estimated water potentials can be made by use of the suggested correction coefficient, and that such adjustments will reduce model bias in estimating water potential of a population of psychrometers.

Verification of the Entire Model

The performance of the model and the relative effectiveness of the correction coefficients for adjusting estimated water potentials were evaluated to verify the applicability of the model. Eight randomly selected psychrometers that had not previously been used were calibrated over the same ranges of conditions for which the model was developed. The model was then used to generate estimated water potentials for each set of conditions based on the microvolt outputs from these psychrometers. Table 6a, b, and c shows the values for actual, estimated, and adjusted-estimated water potentials for each temperature, NaCl molality zero-offset (+60 0, -60 microvolts), and cooling time duration. Correction coefficients were computed from equation 16 for each cooling time and were then used to calculate the adjusted-estimate of water potential using equation 17, similar to the procedures described above.

The sums of the actual, estimated, and adjusted estimates of water potential, together with the correction coefficients and departures for table 6a, b, and c are listed below.

	Table 6a (15 sec)	Table 6b (30 sec)	Table 6c (60 sec)
Σ actual	1270.56	1270.56	1270.56
Σ estimated	1237.38	1281.04	1288.59
Σ act./Σ est.	1.02681	.99182	.98601
Σ adj. est.	1270.56	1270.58	1270.55
Departure (Σ act.–Σ adj. est.)	.00	–.02	.01

Note that only the data for 0 zero-offset was used to compute the correction coefficients in each table in order to test the adjustment procedure at the extreme zero-offsets. Under normal circumstances, most users would calibrate their psychrometers for isothermal conditions only, and would rely on model adjustment with the correction coefficient to remedy any model bias where zero-offsets occur. This, for example, results in reasonably small departures between the actual and adjusted estimates of water potential in table 6. However, even smaller departures should result on the average, when the ratio applied is based on all the data in the tables, including +60 and -60 microvolts. Such computations are shown below to demonstrate the slightly smaller ratios.

	Table 6a (15 sec)	Table 6b (30 sec)	Table 6c (60 sec)
Σ actual	3258.38	3811.68	3663.58
Σ estimated	3218.31	3806.98	3676.11
Σ act./Σ est.	1.01245	1.00123	.99659
Σ adj. est.	3258.38	3811.66	3663.57
Departure (Σ act.–Σ adj. est.)	.00	- 02	–.01

It is somewhat questionable, however, for a user to go through the elaborate calibration under nonisothermal conditions, particularly in view of the relatively small errors that would result from isothermal calibration alone.

The data in table 6 show, in general, that the greatest bias in the model occurs at the extremes of the water potential ranges studies (0.2 m and 1.7 m NaCl). The adjusted-estimates of water potential are usually within ±5 percent of the actual values, even for the extreme ends of the water potential and zero-offset ranges studied. However, the isothermal data are generally predicted more precisely than either zero-offset extreme. The largest departure of the adjusted-estimate from the actual water potential is 9.26 bars, and occurs for the +60 microvolt zero-offset at 60-sec cool time, 35° C (95° F) and 1.7 m NaCl (table 6c). Overall the -60 microvolt zero-offset data tend to depart most from the actual water potential (the largest departure here is in table 6a, for the 15-sec cool time at 15° C (59° F) for the 0.2 m NaCl solution). Because of bias, the model tends to predict lower water potentials than the actual values at the extreme zero-offsets, and yields adjusted estimates that are also slightly lower. Illustrating this point is the majority of lower adjusted estimate values than actual ones in table 6a for the +60 and -60 microvolt zero-offset data.

Although overall trends in the data for each cooling time duration are probably most meaningful, inconsistencies for any one data set are abundant in table 6. For example, in table 6a (15-sec cooling time duration), the 1.5 m NaCl solution at 7.5° C (45.7° F) data show that the two extreme zero-offset water potentials were predicted more precisely than the 0 zero-offset water potential, even though the reverse appears to be the general rule for the data set as a whole. These readily apparent anomalies reflect the variability among psychrometers when calibrated in groups where the data are averaged. Because this variability is retained, even after adjustment with the correction coefficient, adjusted estimates of water potential can be expected to differ from actual values. This effect tends to suggest that psychrometers should be treated as individuals rather than averaged in large groups. However, the intended application and desired level of precision required should form the basis for that decision. If the level of precision achieved in table 6 is sufficient for the given application, then that method of calibration should be used. The time and expense of converting raw microvolt data are greatly reduced when psychrometers can be calibrated and treated in groups.

The variability among psychrometers and model bias is lessened as the cooling time duration is increased from 15 sec to 60 sec (table 6a, b, c). Adjusted estimates of water potential for isothermal data tend to lie within ±3 percent of the actual values regardless of cooling time duration. However, the zero-offset data show a relatively strong effect of increased cooling time duration wherein water potentials are generally underestimated at 15 sec (table 6a) and only slightly overestimated at 60 sec (table 6c). In general, 30-sec cooling time duration (table 6b) appears to provide the best estimates of water potential in terms of departure between the actual and adjusted estimates.

The data in table 6 show that the model adequately (within ±1 sd) predicts water potentials of psychrometers that were not used in its development. Further, these data show that the correction coefficient from equation 16 provides a simple and relatively accurate method of adjusting the model estimates for any given data set. Estimates of water potential under isothermal conditions appear to be quite accurate for either large groups (table 5) or small groups (table 6) of psychrometers. Water potential estimates for nonisothermal conditions. although perhaps not as accurate as those for isothermal conditions, appear to be adequate when a longer cooling time is employed. Although only data for the extreme zero-offset conditions are displayed (+60 and -60 microvolts), these represent the maximum expected departures from actual water potentials, and hence the "worst possible" case. On the other hand, zero-offset data closer to 0 microvolt tend to deviate less, and thus are less variable than those at +60 and -60 microvolts.

Table 6a.—Actual water potentials (bars) of NaCl solutions with 15-second cool time, estimated water potentials by the model, the adjusted-estimate of water potential, and the ratio of the actual to the adjusted-estimate for + 60, 0, and − 60 microvolt of zero-offset for eight new psychrometers

NaCl molality	Water potential	Temperature 0°C +60	0	−60	7.5°C +60	0	−60	15°C +60	0	−60	25°C +60	0	−60	35°C +60	0	−60
	actual	8.36	8.36	8.36	8.60	8.60	8.60	8.84	8.84	8.84	9.15	9.15	9.15	9.46	9.46	9.46
0.2	estimated	8.75	7.51	8.16	9.05	8.58	8.84	9.58	8.49	9.78	9.14	8.73	9.38	9.45	8.48	8.97
	adj. est.	8.94	7.67	8.34	9.25	8.77	9.03	9.79	8.69	10.00	9.34	8.92	9.59	9.66	8.67	9.17
	ratio	.935	1.090	1.002	0.930	.981	.952	.903	1.017	.884	.980	1.026	.954	.979	1.091	1.032
	actual	20.70	20.70	20.70	21.36	21.36	21.36	22.00	22.00	22.00	22.81	22.81	22.81	23.62	23.62	23.62
5	estimated	19.89	19.63	21.01	22.15	22.50	21.95	23.08	21.77	22.28	22.36	22.79	21.63	22.85	22.99	22.84
	adj. est.	20.33	20.06	21.47	22.63	22.99	22.43	23.59	22.24	22.77	22.85	23.29	22.11	23.35	23.50	23.34
	ratio	1.018	1.032	.964	.944	.929	.952	.933	.989	.966	.998	.979	1.032	1.012	1.005	1.022
	actual	29.01	29.01	29.01	29.98	29.98	29.98	30.91	30.91	30.91	32.10	32.10	32.10	33.28	33.28	33.28
.7	estimated	29.64	30.00	30.02	29.39	29.80	30.80	31.46	30.63	32.21	32.44	32.00	33.81	32.81	32.77	32.97
	adj. est.	30.30	30.66	30.68	30.04	30.46	31.47	32.15	31.31	32.92	33.15	32.71	34.55	33.53	33.49	33.70
	ratio	.957	.946	.946	.998	.984	.953	.961	.987	.939	.968	.981	.929	.993	0.994	.988
	actual	41.69	41.69	41.69	43.18	43.18	43.18	44.59	44.59	44.59	46.40	46.40	46.40	48.15	48.15	48.15
1.0	estimated	43.28	40.76	44.26	42.12	39.98	46.32	45.77	43.53	43.66	47.04	46.85	45.82	47.39	47.34	46.37
	adj. est.	44.23	41.66	45.23	43.05	40.86	47.34	46.78	44.49	44.62	48.07	47.88	46.82	48.43	48.38	47.39
	ratio	.943	1.001	.922	1.003	1.057	.912	.953	1.002	.999	.965	.969	.991	.994	0.995	1.016
	actual	63.59	63.59	63.59	66.06	66.06	66.06	68.37	68.37	68.37	71.34	71.34	71.34	74.11	74.11	74.11
1.5	estimated	63.03	64.92	62.89	64.66	65.40	64.68	69.16	67.18	70.63	70.96	72.57	70.54	70.13	74.63	73.21
	adj. est.	64.42	66.35	64.27	66.08	66.84	66.10	70.68	68.66	72.18	72.52	74.17	72.09	71.67	76.27	74.82
	ratio	.987	.958	0.989	1.000	.988	.999	.967	.996	.947	.984	.962	.990	1.034	0.972	.991
	actual	72.60	72.60	72.60	75.50	75.50	75.50	78.20	78.20	78.20	81.70	81.70	81.70	84.90	84.90	84.90
1.7	estimated	66.49	69.10	— *	— *	68.49	— *	76.72	73.76	— *	79.11	77.93	— *	— *	78.27	— *
	adj. est.	67.95	70.62	—	—	69.99	—	78.41	75.38		80.85	79.64			79.99	
	ratio	1.068	1.028	—	—	1.079	—	.997	1.037	—	1.011	1.026	—		1.061	

*Beyond the range of the model.

Table 6b.—Actual water potentials (bars) of NaCl solutions with 30-second cool time, estimated water potentials by the model, the adjusted-estimate of water potential, and the ratio of the actual to the adjusted-estimate for + 60, 0, and − 60 microvolt of zero-offset for eight new psychrometers

NaCl molality	Water potential	Temperature 0°C +60	0	−60	7.5°C +60	0	−60	15°C +60	0	−60	25°C +60	0	−60	35°C +60	0	−60
	actual	8.36	8.36	8.36	8.60	8.60	8.60	8.84	8.84	8.84	9.15	9.15	9.15	9.46	9.46	9.46
0.2	estimated	8.63	8.03	8.49	8.99	9.00	8.53	9.82	8.24	9.94	9.54	8.79	9.31	9.41	8.63	9.96
	adj. est.	8.51	7.92	8.38	8.87	8.88	8.42	9.69	8.13	9.82	9.42	8.68	[illegible]	9.28	8.51	9.83
	ratio	.982	1.056	.998	.970	.968	1.021	.912	1.087	.900	.971	1.054	.996	1.019	1.112	.962
	actual	20.70	20.70	20.70	21.36	21.36	21.36	22.00	22.00	22.00	22.81	22.81	22.81	23.62	23.62	23.62
5	estimated	20.52	21.24	22.14	21.03	22.38	20.49	23.16	22.20	22.06	23.66	23.14	24.36	23.23	23.28	22.47
	adj. est.	20.25	20.97	21.85	20.76	22.09	20.23	22.86	21.92	21.78	23.35	22.84	24.04	22.93	22.98	22.18
	ratio	1.022	.987	.947	1.029	.967	1.056	.962	1.004	1.010	.977	.999	.949	1.030	1.028	1.065
	actual	29.01	29.01	29.01	29.98	29.98	29.98	30.91	30.91	30.91	32.10	32.10	32.10	33.28	33.28	33.28
7	estimated	28.86	29.78	30.57	31.93	30.75	31.35	30.95	31.37	29.16	33.22	32.11	32.03	32.91	33.25	35.48
	adj. est.	28.49	29.40	30.18	31.52	30.35	30.95	30.55	30.97	28.79	32.79	31.70	31.62	32.48	32.82	35.00
	ratio	1.018	.987	.961	.951	.988	.969	1.012	.998	1.074	.979	1.013	1.015	1.025	1.014	.951
	actual	41.69	41.69	41.69	43.18	43.18	43.18	44.59	44.59	44.59	46.40	46.40	46.40	48.15	48.15	[illegible]
1.0	estimated	41.28	42.28	44.47	42.75	41.51	43.99	46.76	43.72	45.98	44.50	46.86	46.52	48.39	48.83	46.85
	adj. est.	40.75	41.74	43.90	42.20	40.97	43.43	46.16	43.16	45.39	43.93	46.26	45.92	47.77	48.20	46.25
	ratio	1.023	.999	.950	1.023	1.054	.994	.966	1.033	.982	[illegible]	1.003	1.010	1.008	.999	[illegible]
	actual	63.59	63.59	63.59	66.06	66.06	66.06	68.37	68.37	68.37	71.34	71.34	71.34	74.11	74.11	74.11
1.5	estimated	65.04	64.67	63.22	66.80	67.59	68.48	67.08	71.37	70.95	70.30	72.66	71.17	71.44	75.52	70.50
	adj. est.	64.20	63.84	62.41	65.94	66.72	67.60	66.22	70.46	70.04	69.40	71.73	70.26	70.53	74.55	69.60
	ratio	.990	.996	1.019	1.002	.990	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	actual	72.60	72.60	72.60	75.50	75.50	75.50	78.20	78.20	78.20	81.70	81.70	81.70	84.90	84.90	84.90
1.7	estimated	67.15	69.97	73.76	69.38	76.76	72.42	77.59	80.55	76.65	78.11	83.09	79.92	81.71	83.47	80.58
	adj. est.	66.29	69.07	72.82	68.49	75.78	71.49	76.60	79.51	75.66	77.11	82.03	78.90	80.66	82.40	79.55
	ratio	1.095	1.051	.997	1.102	.996	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 6c —Actual water potentials (bars) of NaCl solutions with 60 second cool time, estimated water potentials by the model, the adjusted-estimate of water potential, and the ratio of the actual to the adjusted estimate for +60, 0, and −60 microvolt of zero-offset for eight new psychrometers

NaCl molality	Water potential	Temperature 0°C +60	0°C 0	0°C −60	7.5°C +60	7.5°C 0	7.5°C −60	15°C +60	15°C 0	15°C −60	25°C +60	25°C 0	25°C −60	35°C +60	35°C 0	35°C −60
	actual	8.36	8.36	8.36	8.60	8.60	8.60	8.84	8.84	8.84	9.15	9.15	9.15	9.46	9.46	9.46
0.2	estimated	8.51	9.36	8.77	9.88	9.22	8.78	8.64	9.22	9.41	7.92	8.86	8.51	9.88	8.67	10.14
	adj. est.	8.35	9.19	8.61	9.70	9.05	8.62	8.48	9.05	9.23	7.77	8.70	8.35	9.70	8.51	9.95
	ratio	1.001	.910	.971	.887	.950	.998	1.042	.977	.958	1.178	1.052	1.096	.975	1.112	.951
	actual	20.70	20.70	20.70	21.36	21.36	21.36	22.00	22.00	22.00	22.81	22.81	22.81	23.62	23.62	23.62
.5	estimated	20.77	21.22	21.35	21.61	23.01	22.08	23.12	22.83	22.89	23.19	23.68	22.96	22.99	23.48	24.41
	adj. est.	20.38	20.83	20.95	21.21	22.58	21.67	22.69	22.41	22.47	22.76	23.24	22.53	22.56	23.04	23.96
	ratio	1.016	.994	.988	1.007	.946	.986	.970	.982	.979	1.002	0.981	1.012	1.047	1.025	.986
	actual	29.01	29.01	29.01	29.98	29.98	29.98	30.91	30.91	30.91	32.10	32.10	32.10	33.28	33.28	33.28
.7	estimated	29.83	30.40	31.31	30.27	29.94	30.35	32.34	32.08	27.72	32.43	33.36	33.97	32.26	33.75	32.99
	adj. est.	29.27	29.83	30.73	29.17	29.38	29.79	31.74	31.49	27.20	31.82	32.74	33.34	31.66	33.12	32.38
	ratio	.991	.973	.944	1.009	1.020	1.006	.974	.982	1.136	1.009	.980	.963	1.051	1.005	1.028
	actual	41.69	41.69	41.69	43.18	43.18	43.18	44.59	44.59	44.59	46.40	46.40	46.40	48.15	48.15	48.15
1.0	estimated	41.76	41.51	44.51	43.85	41.93	44.07	45.52	44.18	46.31	45.72	47.63	45.78	47.45	46.98	53.35
	adj. est.	40.99	40.74	43.68	43.03	41.15	43.25	44.67	43.36	45.45	44.87	46.74	44.92	46.57	46.11	52.35
	ratio	1.017	1.023	.954	1.003	1.049	.998	.998	1.028	.981	1.034	.993	1.033	1.034	1.044	.920
	actual	63.59	63.59	63.59	66.06	66.06	66.06	68.37	68.37	68.37	71.34	71.34	71.34	74.11	74.11	74.11
1.5	estimated	63.82	65.06	64.77	68.04	65.99	65.87	68.16	69.28	72.13	72.51	72.28	71.37	70.86	74.63	73.06
	adj. est.	62.63	63.85	63.57	66.77	64.77	64.64	66.89	67.99	70.78	71.16	70.94	70.04	69.54	73.24	71.70
	ratio	1.015	.996	1.000	.989	1.020	1.022	1.022	1.006	.966	1.003	1.006	1.019	1.066	1.012	1.034
	actual	72.60	72.60	72.60	75.50	75.50	75.50	78.20	78.20	78.20	81.70	81.70	81.70	84.90	84.90	84.90
1.7	estimated	69.39	74.30	—*	—*	76.52	74.51	78.13	80.07	78.92	77.90	84.19	80.38	73.39	84.96	76.71
	adj. est.	68.10	72.92	—	—	75.10	73.12	76.68	78.58	77.45	76.45	82.63	78.88	72.02	83.38	75.28
	ratio	1.006	.996	—	—	1.005	1.033	1.020	.995	1.010	1.069	.989	1.036	1.179	1.018	1.128

*Beyond the range of the model.

GUIDES FOR USERS

The following suggestions are provided to assist users in application of the calibration model when using screen-caged thermocouple psychrometers similar to those described here. We do not recommend application of the model to other psychrometer designs (such as ceramic cup and end-window designs) under irregular thermal environments until further research can verify their responses to temperature gradients. However, the model does apply to these and any other chromel-constantan psychrometer under the following restrictions:

1. Used under isothermal conditions only,
2. Constructed of 0.0025-cm (0.001-inch) diameter wire with welded junction,
3. Peltier-cooling mode is used with 5 ma current,
4. True temperature and vapor pressure equilibrium is achieved, and
5. Used within the limits of temperature, cooling time duration, and water potential ranges pertinent to the model.

The assumption is that the user has access to computer facilities that will allow the model equations to be programed (appendix I). If this is not possible, the tables in appendix II could be used, but this is far more difficult, time consuming, and subject to interpolation error.

Calibration

1. It is recommended that each individual psychrometer be calibrated under isothermal conditions at three different water potentials and at one temperature within the range of anticipated need. For most general applications the 0.5, 1.0, and 1.5 m NaCl solutions should be used at 25° C (77° F). Only one temperature is required since psychrometer response to this variable is far more predictable than to water potential. However, other solutions and temperatures can be used if the anticipated conditions for use are specifically known. In any case, three calibration solutions representing the near-extremes and middle range of water potentials are recommended. Outputs should be recorded to the nearest 0.1 microvolt. It is further recommended that

calibration *not* be attempted under nonisothermal conditions to achieve zero-offset data points. This is an extremely complex process that may lead to more confusion than is warranted. The model adequately predicts water potentials under these conditions.

2. For most general applications it is recommended that the 30-sec cool time duration be used throughout. Shorter cooling times may be justified in those cases where length of time between readings is crucial, but generally less precise estimates of water potential will result and the variability among psychrometers will likely be greater. Longer cooling times, up to 60 sec, generally do not appear to offer any strong advantages over the 30-sec cooling times, and also may unnecessarily prolong the length of time between readings. This is an important logistical problem when attempting to read large numbers of psychrometers during a specified time.

3. Although calibration should ideally be conducted under carefully controlled temperatures in a water bath, suitable conditions can be achieved in a well-insulated water reservoir. For example, large picnic jugs, vacuum bottles, or insulated ice chests have all been used successfully with normal precautions to minimize rapid temperature fluctuations. Water temperature can be adjusted to that of the external environment to lessen the possibilities of temperature gradients.

Model Application

1. For the most accurate estimates of water potential, each psychrometer should be calibrated and its microvolt data be converted to water potential separately. Compute the ratio of actual to estimated water potential (equation 16) for each psychrometer. For example, the sum of the water potentials of the three NaCl solutions used divided by the sum of the water potentials predicted by the model for the microvolt outputs of that psychrometer provides the correction coefficient.

2. Each psychrometer is now assigned a unique correction coefficient (or B value). Model estimates of water potential, whether obtained from the computer program (appendix I) or the tables (appendix II), made from data collected with that psychrometer are multiplied by this correction coefficient to obtain the adjusted estimate of water potential (equation 17). If the computer program is used, attention is called to step 61 in the BASIC program and step 8 in the FORTRAN program (where B = 1.0 presently), which must be changed to the new correction coefficient. Also, insert the appropriate cooling time in seconds in step 9 of the FORTRAN program (where sec = 15, presently).

3. For applications requiring large numbers of psychrometers, a single correction coefficient may be computed for the entire group. The principal advantage in this technique is that considerable time can be conserved during computation of data. The main disadvantage is that some loss in precision of water potential estimates results due to the variability in microvolt output characteristics among the psychrometers used. If this procedure is used, discard all psychrometers with calibration data that display a greater variability than ± 1 sd from the mean of the entire population.

4. Occasionally a particular psychrometer may be more sensitive at low water potentials than those used to develop the model. In such cases its microvolt output may exceed the range of the model, and its water potential may not be calculated. This is most likely to occur at low water potentials near the lower limits of the model (about -75 to -85 bars). In such cases, which are anticipated to be very few, the data will have to be excluded from computation by the model and computed by hand from standard calibration curves.

Data Acquisition

1. For general laboratory use, psychrometers should be kept as clean and free of contaminants as possible to insure accurate data. The ultimate acquisition of reliable data depends more upon the user than the model. Precautionary measures to be followed are discussed in Brown and Van Haveren (1972), Brown (1970), and Wiebe and others (1971).

2. During field use, efforts must be made to minimize temperature gradients. For *in situ* measurements of soil water potential, psychrometers should be buried in a horizontal position (Wiebe and others 1977; Wiebe and Brown 1979). The time when they are read during the day should be selected, if possible, to minimize temperature gradients. Season of the year may also affect the time of day selected. Samples collected and read in the field must also be protected from temperature gradients and other influences that may affect data. The meter or data gathering instrument must be shaded from direct solar insolution.

3. Raw microvolt data, together with recorded temperatures, zero-offsets, and the appropriate cooling time duration are required for each computation of water potential by the model. The model estimate of water potential is then multiplied by the appropriate correction coefficient to obtain the adjusted estimate of water potential. If desired, water potentials expressed in bars by the model may be converted to the international term of MPa (mega Pascals) by multiplying bars times 0.1.

CONCLUSIONS

The outputs of Peltier thermocouple psychrometers are quite predictable at different cooling times, temperatures, temperature gradients, and water potentials. Responses to water potential are probably the weakest link in a modeling effort because of the variability among psychrometers in terms of construction techniques and the configuration of their components. Some of the contributing variables are the precise chemistry of the welded sensing junction, the length of chromel and constantan lead wires of the thermocouple, the geometric position of the sensing junction, and the freedom with which water vapor can be exchanged between the evaporating source and the psychrometer cavity. However, psychrometer responses to temperature, temperature gradients (within limits of unit size and materials used in construction), and cool times are all virtually fixed with far fewer possibilities for variation.

Generally, the model predicts water potentials most precisely for isothermal conditions at the longer cool times (30 to 60 sec). The greatest bias occurs at the extreme water potentials, particularly near the lower limits of psychrometer sensitivity (about -80 bars), with the 15-sec cool time. Also, generally model bias is greater near the extreme zero-offsets (approaching ± 60 microvolts), although this is relatively small. Based on these limitations, it is recommended that psychrometers be calibrated at several water potentials under isothermal conditions at some intermediate temperature and cool time before use. Those units displaying a greater variability than ± 1 sd from the mean of the entire population should be discarded.

Absolute precision of water potential measurements with thermocouple psychrometers is probably not possible except under unusual circumstance. However, the model is designed to predict water potential precisely as described by psychrometer calibration data. Thus, it is more the care taken by the user during calibration and use of psychrometers that determines the precision of water potential values than it is the ability of the model to predict them. Hand-drawn calibration curves, as generally developed at present, do not provide the same levels of sensitivity and consistency for estimating water potentials as the model given here for the smoothed interactive effects of the four independent variables involved. Extensive calibration trials and data points for each psychrometer over a range of numerous temperatures and water potentials provide little or no assurance that water potential data will be any more accurate than that computed by the methods suggested.

Comparisons of water potential estimates made by both the model and hand-drawn calibration curves suggest some advantages of the model. The model will consistently calculate water potentials for the entire range of conditions specified, and will do so for whatever level of fractional input is desired. Hand-drawn curves, on the other hand, yield water potential data that are subject to numerous additional errors. The physical process of plotting data points, fitting curves, and then interpreting data from them is contingent upon extreme care tempered with abundant quantities of expensive time. The very best hand-drawn curves yield only an approximate water potential, even if a set of curves is drawn for each individual psychrometer. We found that, not only can two different technicians read the same graph differently, but the same technician may make widely varying interpretations from the same graph at different times. One of the most common errors was interpreting data from the wrong graph—and, very often even these were read incorrectly. Thus, the magnitude of the error in data interpreted from hand-drawn curves was most often greater than that associated with the model.

Since there is no simple factor that can be applied to water potential data to correct it for temperature gradients, the number of calibration curves that would be needed for each psychrometer to cover all specified conditions is beyond the limits of practicality. The magnitude of the effort just to interpret large numbers of observations from hand-drawn curves is overwhelming. Whether a study involves a few data points from one psychrometer, or numerous data points from hundreds of psychrometers, use of the calibration model promises to reduce the time and magnitude of the errors normally inherent in this kind of research.

Based on the performance and verification of the predictive model, the hypotheses originally posed are all accepted. The responses of any given psychrometer of similar construction to those used here can be predicted for the conditions specified to at least within the limits of error normally expected with hand-drawn curves. The normal limits of error of predicted water potentials can be narrowed by adjusting the model based on only one or a few calibration points. The time and expense normally devoted to calibration can be significantly reduced with the assurance that normal limits of error are not jeopardized. Also, large quantities of either field or laboratory data can be analyzed more quickly and with fewer errors using the model than with conventional methods.

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APPENDIX I

COMPUTER PROGRAM IN BASIC AND FORTRAN

Computer programs of the predictive calibration model; (A) in BASIC and (B) in FORTRAN. Text and related computer acronyms are defined in C for the FORTRAN program.

APPENDIX I A

Enhanced BASIC program for Hewlett-Packard 9845-B

```
10     REM     RAY BROWNS WATER POTENTIAL EQUATION
20     OPTION BASE 1
30     ON ERROR GOTO 440
40     INPUT "INPUT THE NUMBER OF SETS OF OBSERVATIONS-THEN PRESS CONT.",Z  !TOTA
L SETS OF FOUR NUMBERS TO BE USED
50     B=1
60     FOR J=1 TO Z
70        INPUT "INPUT MV,ZERO OFFSET,TEMP.,SECONDS,-THEN PRESS CONT.",Mv,Omv,T,S
ec
80        Yp1=39.2-.0004346*(60-Sec)^2.45  !YP'
90        Int=12.1-.003475*(60-Sec)^1.63
100       Yp=Int+.017288*Yp1*T^1.1
110       Yp15=12.1-.003475*(60-15)^1.63+(39.2-.0004346*(60-15)^2.45)*.017288*T^1
.1  !YP SOLVED AT 15 SECONDS
120       Yp2=8.4+2.734E-7*(60-Sec)^3.97
130       Ui=88-2.579E-4*(60-Sec)^2.7
140       Xp=-(Ui-Yp2*.00017185*(40-T)^2.35)
150       Xp15=-(88-2.579E-4*(60-15)^2.7-(8.4+2.734E-7*(60-15)^3.97)*.00017185*(4
0-T)^2.35)  !XP SOLVED AT 15 SECONDS
160       Ii=.45+3.33E-4*Sec+1.9846E-19*Sec^10
170       Ia=.45+3.33E-4*15+1.9846E-19*15^10  !IiSOLVED FOR USE WITH N15
180       Ni=2.5+EXP(-(ABS((60-Sec)/60-1)/.405)^3)
190       Na=2.5+EXP(-(ABS((60-15)/60-1)/.405)^3)  !Ni SOLVED FOR USE WITH N15
200       N=1.18+.185*((EXP(-ABS(((40-T)/40-1)/(1-Ii))^Ni)-EXP(-(1/(1-Ii))^Ni))/(
1-EXP(-(1/(1-Ii))^Ni)))
210       N15=1.18+.185*((EXP(-ABS(((40-T)/40-1)/(1-Ia))^Na)-EXP(-(1/(1-Ia))^Na))
/(1-EXP(-(1/(1-Ia))^Na)))  !N SOLVED AT 15 SECONDS
220       C1=Yp-Yp/ABS(Xp)^N*ABS(Xp--22.5)^N  ! NUMERATOR FOR SOLVING C
230       C2=Yp15-Yp15/ABS(Xp15)^N15*ABS(Xp15--22.5)^N15  ! DENOMINATOR FOR C
240       C3=C1/C2*(.015*Omv+.001471*T*Omv)
260       C=(C3+C1)/C1
270       Wp=(ABS(Xp)^N*(Yp*C*B-Mv)/(Yp*C*B))^(1/N)+Xp
280       GOSUB Print
290       NEXT J
300    PRINTER IS 16
310    PRINT "THIS PROGRAM IS FINISHED TO RESTART PRESS RUN"
320    END
330 Print:  ! PRINTING ROUTINE
340    PRINTER IS 7,1,WIDTH(120)
350    PRINT USING 360,"***",J,"***"
360    IMAGE 16X3A,2D,3A
370    PRINT USING 390;"1.","MICROVOLTS=",Mv,"MICROVOLTS","2.","ZERO OFFSET=",Omv
,"MICROVOLTS","3.","TEMPERATURE=",T,"CENT.","4.","COOL TIME=",Sec,"SECONDS"
380    PRINT USING 390;"5.","WATER POTENTIAL=",Wp,"BARS"
390    IMAGE 2A4X,15A4X,M2D.2D4X,12A/
400    PRINT
410    PRINT
420    IF J MOD 8=0 THEN PRINT PAGE
430    RETURN
440    PRINTER IS 7,1,WIDTH(120)
450    PRINT USING 460,"***",J,"***"
460    IMAGE 16X3A,2D,3A
470    PRINT
480    PRINT "ERROR HAS OCCURED, YOU HAVE EXCEEDED THE PEAK."
490    PRINT
500    PRINT "****YOUR INPUT WAS****"
510    PRINT
520    PRINT USING 530,"1.","MICROVOLTS=",Mv,"MICROVOLTS","2.","ZERO OFFSET=",Omv
,"MICROVOLTS","3.","TEMPERATURE=",T,"CENT.","4.","COOLTIME=",Sec,"SECONDS"
530    IMAGE 2A4X,15A4X,M2D.2D4X,12A/
540    PRINT
550    PRINT
560    IF J MOD 8=0 THEN PRINT PAGE
570    GOTO 290
```

APPENDIX I B

FORTRAN IV Program for water potential

```
(Place system cards here)
      DIMENSION TEMPX(5),OMVX(13),LTRS(16),WPS(13)
      REAL MV,MS,M15,IS,I15,LNS,LN15,NS,N15,MVS,MV15
      DATA IBLNK/' '/,WPS/13*0./,
     *LTRS/'M','I','C','R','O','V','O','L','T',
     *'R','E','A','D','I','N','G'/,
     *TEMPX/0.,7.5,15.,25.,35./,
     *OMVX/-60.,-50.,-40.,-30.,-20.,-10.,0.,10.,20.,30.,40.,50.,60./
      B = 1.
      SEC = 15
      WPK = -22.5
      IPAGE = 0
      DO 99 J=1,5
      LNN = 1
      TEMP = TEMPX(J)
      IPAGE = IPAGE + 1
      PRINT 101,IPAGE,SEC, TEMPX(J)
      PRINT 102
      PRINT 103
      PRINT 104
      PRINT 103
      PRINT 105
      DO 99 K=1,70
      NWPS= 0
      MV = K
      DO 15 L=1,13
      OMV = OMVX(L)
      M15=3.2904052
      MS=2.5+EXP(-(ABS(((60-SEC)/60-1)/.405)**3))
      IS=.45+.000333*SEC+1.9846E-19*SEC**10
      I15=.4549951
      LNS=EXP(-(ABS(((40-TEMP)/40-1)/(1-IS))**MS))
      LN15=EXP(-(ABS(((40-TEMP)/40-1)/(1-I15))**M15))
      RNS=EXP(-((1/(1-IS))**MS))
      RN15=EXP(-((1/(1-I15))**M15))
      DS=1-RNS
      D15=1-RN15
      NS=((LNS-RNS)/DS)*.185+1.18
      N15=((LN15-RN15)/D15)*.185+1.18
      $1AS=12.1-.003475*(60-SEC)**1.63
      $1A15=10.3793553
      $1YS=39.2-.0004346*(60-SEC)**2.45
      $1Y15=34.3195442
      UIS=$1AS+.017288*$1YS*TEMP**1.1
      UI15=$1A15+.017288*$1Y15*TEMP**1.1
      $2AS=88-.0002579*(60-SEC)**2.7
      $2A15=80.4988970
      $2YS=8.4+2.734E-07*(60-SEC)**3.97
      $2Y15=9.4001202
      SPS=($2AS-$2YS*.00017185*(40-TEMP)**2.35)*(-1)
      SP15=($2A15-$2Y15*.00017185*(40-TEMP)**2.35)*(-1)
      ZOE=(.015*OMV+.001471*OMV*TEMP)
      MVS=(UIS-(UIS/(ABS(SPS)**NS))*(ABS(SPS-WPK)**NS))
```

```
      MV15=(UI15-(UI15/(ABS(SP15)**N15))*(ABS(SP15-WPK)**N15))
      C=(MVS+(MVS/MV15)*ZOE)/MVS
      R=UIS*C
      IF(MV.GT.R)GO TO 10
      WP=((((ABS(SPS)**NS)*(UIS*C-MV))/(UIS*C))**(1/NS)+SPS)*B
      WP = WP*(-1.)
      GO TO 12
   10 WP = 0.
   12 IF (WP.EQ. 0.) GO TO 15
      NWPS = NWPS + 1
      WPS(NWPS)=WP
   15 CONTINUE
   17 DO 18 II=6,78,6
      IF (LNN .EQ. II) GO TO 19
   18 CONTINUE
      GO TO 20
   19 PRINT 103
      LNN = LNN + 1
   20 LABL = 0
      DO 21 II=25,57,2
      LABL = LABL + 1
      IF (II .EQ. LNN) GO TO 22
   21 CONTINUE
      IHD1 = IBLNK
      GO TO 60
   22 GO TO (25,27,29,31,33,35,37,39,41,43,45,47,49,51,53,55,57),LABL
   25 IHD1 = LTRS(1)
      GO TO 60
   27 IHD1 = LTRS(2)
      GO TO 60
   29 IHD1 = LTRS(3)
      GO TO 60
   31 IHD1 = LTRS(4)
      GO TO 60
   33 IHD1 = LTRS(5)
      GO TO 60
   35 IHD1 = LTRS(6)
      GO TO 60
   37 IHD1 = LTRS(7)
      GO TO 60
   39 IHD1 = LTRS(8)
      GO TO 60
   41 IHD1 = LTRS(9)
      GO TO 60
   43 IHD1 = IBLNK
      GO TO 60
   45 IHD1 = LTRS(10)
      GO TO 60
   47 IHD1 = LTRS(11)
      GO TO 60
   49 IHD1 = LTRS(12)
      GO TO 60
   51 IHD1 = LTRS(13)
      GO TO 60
   53 IHD1 = LTRS(14)
```

```
      GO TO 60
   55 IHD1 = LTRS(15)
      GO TO 60
   57 IHD1 = LTRS(16)
   60 IHD2 = K
      IF (NWPS.NE.0) GO TO 62
      PRINT 107,IHD1,IHD2
      GO TO 78
   62 GO TO (63,64,65,66,67,68,69,70,71,72,73,74,75),NWPS
   63 PRINT 110,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   64 PRINT 111 ,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   65 PRINT 112,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   66 PRINT 113,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   67 PRINT 114,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   68 PRINT 115,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   69 PRINT 116,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   70 PRINT 117,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   71 PRINT 118,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   72 PRINT 119,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   73 PRINT 120,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   74 PRINT 121,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
      GO TO 78
   75 PRINT 122,IHD1,IHD2,(WPS(JJ),JJ=1,NWPS)
   78 LNN = LNN + 1
      DO 80 MM=1,NWPS
   80 WPS(MM) = 0.
   99 CONTINUE
  100 STOP
  101 FORMAT ('1',55X,'PREDICTED WATER POTENTIAL',33X,I3/'0',28X,
     *'COOLING TIME IN SECONDS ---------------- ',F5.1/
     *' ',28X,'PSYCHROMETER TEMPERATURE, CENTIGRADE --- ',F5.1/' ')
  102 FORMAT ('0',53X,'OFFSET FROM ZERO IN MICROVOLTS')
  103 FORMAT (' ',28X,5('-----+'),'-----* -----* ',5('-----+'),
     *'-----')
  104 FORMAT (' ',28X,'  -60   -50   -40   -30   -20   -10      0      +
     *10   +20   +30   +40   +50   +60')
  105 FORMAT (' ',53X,'WATER POTENTIAL, NEGATIVE BARS'/' ')
  110 FORMAT (' ',19X,A1,2X,I2,81X,F4.1)
  111 FORMAT (' ',19X,A1,2X,I2,73X,2(2X,F4.1))
  112 FORMAT (' ',19X,A1,2X,I2,67X,3(2X,F4.1))
  113 FORMAT (' ',19X,A1,2X,I2,61X,4(2X,F4.1))
  114 FORMAT (' ',19X,A1,2X,I2,55X,5(2X,F4.1))
  115 FORMAT (' ',19X,A1,2X,I2,49X,6(2X,F4.1))
  116 FORMAT (' ',19X,A1,2X,I2,43X,F4.1,2X,6(2X,F4.1))
```

```
163.      117  FORMAT (' ',19X,A1,2X,I2,35X,F4.1,4X,F4.1,2X,6(2X,F4.1))
164.      118  FORMAT (' ',19X,A1,2X,I2,27X,2(2X,F4.1),4X,F4.1,2X,6(2X,F4.1))
165.      119  FORMAT (' ',19X,A1,2X,I2,21X,3(2X,F4.1),4X,F4.1,2X,6(2X,F4.1))
166.      120  FORMAT (' ',19X,A1,2X,I2,15X,4(2X,F4.1),4X,F4.1,2X,6(2X,F4.1))
167.      121  FORMAT (' ',19X,A1,2X,I2,9X,5(2X,F4.1),4X,F4.1,2X,6(2X,F4.1))
168.      122  FORMAT (' ',19X,A1,2X,I2,3X,6(2X,F4.1),4X,F4.1,2X,6(2X,F4.1))
169.      107  FORMAT (' ',19X,A1,2X,I2)
170.     C         LIMITS OF APPLICATION:
171.     C             14< SEC < 61
172.     C             -1 < TEMP, DEGREE CEN < 41
173.     C             MV < OR EQUAL TO VIS*B*C
174.     C            -61 < OMV < 61
175.           DEBUG SUBCHK
176.           END
```

Note that statements 1 through 176 comprise the program necessary to table output on any computer. Only systems cards and minor programming conventions peculiar to the computer to be used, need be altered.

APPENDIX I C

Text variable	Related computer variables and explanation	
SEC.	SEC:	microvolt observation, time in seconds
TEMP	TEMP:	temperature in degrees centigrade, in soil medium
MV	MV:	actual microvolt reading
	MVS:	estimated microvolt reading for variable seconds
	MV15:	estimated microvolt reading for 15 sec
WP	WP:	estimated water potential for MV period of observation
UI	UIS:	upper intercept for estimated MV curves, variable seconds
	UI15:	as above, for 15 sec
SP	SPS:	water potential at which the curve of estimated MV peaks, for variable seconds
	SP15:	as above, for 15 sec
N	NS:	power of the WP-effect for variable seconds
	N15:	as above, for 15 sec
M	MS:	power of the sigmoid describing N, variable seconds
	M15:	as above, for 15 sec
I	IS:	inflection point of the sigmoid describing N, variable seconds
	I15:	as above, for 15 sec
-	LNS:	left numerator of the sigmoid describing N, variable seconds
-	LN15	as above, for 15 sec
-	RNS:	right numerator of the sigmoid describing N, variable seconds
-	RN15:	as above, for 15 sec
-	DS:	denominator of the sigmoid describing N, variable seconds
-	D15:	as above, for 15 sec
INT1	$1AS:	intercept for UIS descriptor, at variable sec
	$A15:	intercept for UI15 descriptor, at 15 sec
YP1	$1YS:	scaling height of TEMP-effect in UIS, at variable seconds
	$1Y15:	scaling height of TEMP-effect in UI15, at 15 sec
INT2	$2AS;	intercept for SPS descriptor, at variable seconds
	$2A15:	intercept for SP15 descriptor, at 15 sec
YP2	$2YS:	scaling height of TEMP-effect in SPS, at variable seconds
	$2Y15:	scaling height of TEMP-effect in SP15, at 15 sec
BIAS	ZOE:	zero offset effect
OMV	OMV:	offset microvolts due to temperature differential at thermocouple points
-	WPK:	= WP of-22.5, a constant
C	C:	correction in MV estimate due to OMV
B	B:	least squares fitting coefficient for the MV model
-	R:	UIS*B*C

APPENDIX II

COMPUTER PRINTOUT OF MODEL

Computer printout of predicted water potentials in bars for the temperature range of 0° to 40° C (32° to 104° F), microvolt output, cool time in sec, and zero-offset in 10-microvolt intervals from −60 to +60 microvolts. All water potential values are unadjusted.

COOLING TIME IN SE[illegible]ONDS ------------

1						[illegible]4.9					
	13			11.1							
			17.7	17.0							
4											
				29.5							
	44	41.9								[illegible]7.7	
	[illegible]	50.9			41.6				[illegible]4.1		
	67	61.8		51.7		44.9	4[illegible].1	41.4			
			65.8	61.4							
											[illegible].4

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60
67

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 1.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	[illegible]	6.0	5.7	5.5	5.2	5.0	4.8	4.7	4.5	4.4	4.2	4.1	3.9
	2	[illegible]	[illegible]	11.6	11.1	10.6	10.2	9.8	9.5	9.1	8.8	8.5	8.2	8.0
	3	[illegible]	[illegible]	17.7	16.9	16.2	15.6	14.9	14.4	13.9	13.4	12.9	12.5	12.1
	4	[illegible]	25.3	24.1	[illegible]	22.0	21.1	20.2	19.5	18.8	18.1	17.5	16.9	16.4
	5	[illegible]	[illegible]	[illegible]	29.4	28.0	26.9	25.8	24.8	23.8	23.0	22.2	21.4	20.7
	6	42.3	[illegible]	37.9	36.1	34.4	[illegible]	31.5	30.3	29.1	28.0	27.0	26.1	25.2
	7	51.4	48.4	45.7	43.3	41.2	39.3	37.6	36.0	34.6	33.3	32.1	30.9	29.9
	8	62.5	58.0	54.4	51.3	48.6	46.3	44.1	42.2	40.4	38.8	37.4	36.0	34.7
	9			65.4	[illegible]	57.1	54.0	51.3	48.9	46.7	44.8	43.0	41.4	39.9
	10					68.3	63.3	59.5	56.4	53.6	51.2	49.0	47.1	45.3
	11								65.7	61.7	58.5	55.8	53.3	51.2
	12										68.1	63.8	60.6	57.8
	13												71.0	65.9
	14													
	15													
	16													
	17													
	18													
	19													
	20													
M	21													
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[illegible]

[illegible] METER TEMPERATURE, CENTIGRADE ---

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

1												
2												
3	18.6	17.7	16.9	16.1	15.4	14.7	14.1	13.6				
4												
5												
6												
7	48.5	45.6	43.1	40.8	38.8	37.0	35.3	33.8	32.5	31.2	30.1	29.
8												
9		65.0	60.1	56.3	53.1	50.3	47.8	45.6	43.6	41.7	40.1	
10				66.7	61.9	58.1	54.9	52.2	49.7	47.5	45.5	43.7	42.1
11						68.4	63.4	59.7	56.6	53.9	51.5	49.3	47.3
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14													67.5
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 3.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	WATER POTENTIAL, NEGATIVE BARS												
1	5.7	5.4	5.2	4.9	4.7	4.5	4.4	4.2	4.0	3.9	3.8	3.6	3.5
2	11.6	11.1	10.5	10.0	9.6	9.2	8.8	8.5	8.2	7.9	7.6	7.3	7.1
3	17.8	16.9	16.0	15.3	14.6	14.0	13.4	12.9	12.4	11.9	11.5	11.1	10.7
4	24.2	22.9	21.7	20.7	19.7	18.9	18.1	17.4	16.7	16.1	15.5	15.0	14.5
5	30.9	29.2	27.7	26.3	25.1	24.0	23.0	22.0	21.2	20.4	19.6	18.9	18.3
6	38.0	35.9	33.9	32.2	30.7	29.3	28.0	26.8	25.8	24.8	23.9	23.0	22.2
7	45.8	43.0	40.6	38.5	36.5	34.8	33.3	31.8	30.5	29.3	28.2	27.2	26.2
8	54.4	50.9	47.8	45.1	42.8	40.7	38.8	37.1	35.5	34.1	32.8	31.5	30.4
9	65.1	59.9	55.9	52.5	49.5	47.0	44.7	42.6	40.7	39.0	37.5	36.1	34.7
10			65.9	61.0	57.1	53.9	51.0	48.5	46.3	44.3	42.5	40.8	39.3
11					66.6	61.9	58.2	55.1	52.4	49.9	47.8	45.8	44.0
12							67.2	62.7	59.2	56.1	53.5	51.2	49.1
13									67.7	63.4	60.0	57.1	54.5
14											68.2	64.0	60.7
15													68.6
16													
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PREDICTED WATER POTENTIAL

PSYCHROMETER TEMPERATURE, CENTIGRADE --- 4.9

2	11.1	10.5	10.0	9.5	9.1	8.7	8.4	8.0	7.7	7.4	7.2	6.9	6.7
4	23.0	21.8	20.7	19.6	18.7	17.9	17.1	16.4	15.8	15.2	14.6	14.1	13.7
7	43.3	40.7	38.4	36.3	34.5	32.9	31.4	30.0	28.8	27.6	26.6	25.6	24.7
8	51.2	47.9	45.0	42.5	40.3	38.3	36.5	34.9	33.4	3.			
9	60.3	55.9	52.3	49.2	46.5	44.1	41.9	40.0	38.2	36.6	35.2	33.	
13							71.0	65.4	61.4	58.1	55.3	52.8	50.5
16													69.4

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 5.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	5.2	[illegible]	4.7	4.6	[illegible]	4.1	3.9	3.8	3.6	3.5	3.4	3.3	3.1
2	10.6	[illegible]	9.6	9.1	8.7	8.3	7.9	7.6	7.3	7.1	6.8	6.6	6.3
3	16.2	[illegible]	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.7	10.3	9.9	9.6
4	22.0	[illegible]	19.7	18.7	17.8	17.0	16.3	15.6	15.0	14.4	13.9	13.4	12.9
5	28.0	[illegible]	25.0	23.7	22.6	21.5	20.6	19.7	18.9	18.2	17.5	16.9	16.3
6	34.3	[illegible]	30.5	[illegible]	27.5	26.2	25.0	24.0	[illegible]	22.1	21.3	20.5	19.8
7	41.0	[illegible]	36.3	[illegible]	32.6	31.1	29.7	28.4	[illegible]	26.1	25.1	24.2	23.3
8	48.3	[illegible]	42.5	[illegible]	38.0	36.2	34.5	[illegible]	[illegible]	30.2	29.0	28.0	26.9
9	56.4	[illegible]	49.1	[illegible]	43.7	41.5	39.5	37.7	[illegible]	34.5	33.1	31.9	30.7
10	66.4	[illegible]	[illegible]	[illegible]	49.9	47.2	44.8	42.6	40.7	39.0	37.4	35.9	34.6
11		73.2	65.4	60.5	[illegible]	53.3	50.5	47.9	45.7	43.6	41.8	40.1	38.6
12				70.7	[illegible]	60.3	56.7	[illegible]	51.0	48.6	46.5	44.5	42.7
13						69.1	64.0	[illegible]	56.8	54.0	51.4	49.2	47.1
14								[illegible]	63.5	59.9	56.9	54.2	51.8
15									73.4	67.1	63.0	59.8	56.9
16											71.3	66.3	62.7
17													70.0
18													
19													
20													
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PREDICTED WATER [illegible]

[illegible]

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	1	5.0	4.8	4.5	4.3	4.1	3.9	3.7	3.6	3.5	3.3	3.2	3.1	3.0
	2	10.2	9.6	9.1	8.7	8.3	7.9	7.6	7.3	7.0	6.7	6.5	6.2	6.0
	3	15.5	14.6	13.9	13.2	12.6	12.0	11.5	11.0	10.6	10.2	9.8	9.4	9.1
	4	21.0	19.8	18.8	17.8	17.0	16.2	15.5	14.8	14.2	13.7	13.2	12.7	12.3
	5	26.7	25.2	23.8	22.6	21.5	20.5	19.6	18.7	18.0	17.3	16.6	16.0	15.5
	6	32.7	30.7	29.0	27.5	26.1	24.9	23.8	22.8	21.8	21.0	20.2	19.4	18.7
	7	39.0	36.6	34.5	32.6	31.0	29.5	28.1	26.9	25.8	24.7	23.8	22.9	22.1
	8	45.7	42.8	40.3	38.0	36.0	34.2	32.6	31.2	29.8	28.6	27.5	26.4	25.5
	9	53.1	49.5	46.4	43.7	41.3	39.2	37.3	35.6	34.0	32.6	31.3	30.1	29.0
	10	61.6	56.9	53.1	49.8	47.0	44.4	42.2	40.2	38.4	36.8	35.3	33.9	32.6
	11		65.9	60.7	56.5	53.0	50.1	47.4	45.1	43.0	41.1	39.4	37.8	36.3
	12			70.6	64.4	59.9	56.2	53.0	50.3	47.8	45.6	43.6	41.8	40.2
	13						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	14						73.4	66.7	62.3	58.7	55.7	53.0	50.6	48.5
	15								[illegible]	[illegible]	[illegible]			
	16										68.6	64.3	60.8	57.9
	17											72.6	67.2	63.4
	18													70.4
	19													
	20													
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I	23													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 7.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	4.[illegible]	4.[illegible]	4.3	4.1	3.9	3.7	[illegible]	3.4	3.3	3.2	3.1	3.0	2.9
[illegible]	[illegible]	[illegible].2	8.7	[illegible].3	7.9	7.[illegible]	7.[illegible]	6.9	6.7	6.4	6.2	5.9	5.7
[illegible]	14.[illegible]	14.0	13.3	12.6	12.0	11.5	11.0	10.5	10.1	9.7	9.3	9.0	8.7
4	[illegible].1	[illegible].9	17.[illegible]	17.[illegible]	16.[illegible]	15.4	14.[illegible]	14.1	13.6	13.0	12.5	12.1	11.7
5	25.5	24.0	22.7	21.[illegible]	20.[illegible]	19.5	18.6	17.8	17.1	16.4	15.8	15.2	14.7
[illegible]	[illegible].2	[illegible].3	27.7	[illegible].2	24.9	23.7	22.6	21.7	20.8	19.9	19.2	18.4	17.8
[illegible]	37.[illegible]	34.[illegible]	[illegible]	[illegible].1	29.5	28.[illegible]	26.7	25.6	24.5	23.5	22.6	21.7	20.9
[illegible]	43.4	40.7	38.[illegible]	[illegible].1	34.2	32.[illegible]	31.0	29.6	28.3	27.1	26.1	25.1	24.2
[illegible]	[illegible].2	4[illegible]	44.[illegible]	41.4	39.2	37.2	[illegible].4	33.7	32.3	30.9	29.7	28.5	27.5
1[illegible]	57.6	53.6	[illegible].1	47.0	44.4	42.[illegible]	39.9	38.1	36.4	34.8	33.4	32.1	30.9
11	[illegible]7.1	61.[illegible]	56.8	53.1	50.0	47.2	44.8	42.6	40.6	38.8	37.2	35.7	34.3
12		71.5	64.7	59.9	5[illegible].[illegible]	52.7	49.9	47.3	45.1	43.0	41.2	39.5	37.9
13				68.3	63.[illegible]	5[illegible].8	55.4	52.4	49.8	47.4	45.3	43.4	41.7
14					72.[illegible]	6[illegible].9	61.6	57.9	54.8	52.1	49.7	47.5	45.6
15							69.2	64.3	60.4	57.2	54.4	51.9	49.6
16								73.0	67.0	62.9	59.5	56.6	54.0
17										70.0	65.4	61.8	58.7
18											73.7	67.9	64.0
19													70.6
20													
M 21													
[illegible]													
I [illegible]													
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PSYCHROMETER TEMPERATURE, CENTIGRADE

OFFSET FROM [illegible]

1	[illegible]	[illegible]	4.1	3.9									
2	[illegible]	[illegible]	[illegible]	5.0						6.1			
3	14.[illegible]	[illegible]4											
4	[illegible]	[illegible]	17.[illegible]	16.3	[illegible]			13.5		12.4	12.0		
5	[illegible].4		21.7		19.[illegible]								
6	[illegible]	28.[illegible]	[illegible]	25.0	[illegible]								
7	35.[illegible]			29.6								20.7	
8	41.4	[illegible].7	[illegible]	34.4									
9	47.[illegible]	[illegible].5	41.[illegible]	39.4								27.1	
10	54.[illegible]		[illegible]					36.1	34.5	33.0	31.7	30.4	
11	[illegible].6	57.[illegible]	[illegible]6	50.2		[illegible].7							
12	[illegible].7			56.3						40.7		37.4	
13								[illegible].1	47.0	44.8	42.8	41.0	
14													
15									56.5		51.1		
16									62.0				50.7
17													
18										71.2			59.4
19											74.7		

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 9.0

OFFSET FROM ZERO IN MICROVOLTS

	-6	-5	-4	-3	-2	-1	0	+10	+20	+30	+40	+50	+60
	WATER POTENTIAL, NEGATIVE BARS												
1	4.5	4.2	4.0	3.8	3.6	3.4	3.3	3.2	3.0	2.9	2.8	2.7	2.6
2	9.0	8.5	8.1	7.6	7.3	6.9	6.6	6.4	6.1	5.9	5.6	5.4	5.2
3	13.7	12.9	12.2	11.6	11.0	10.5	10.0	9.6	9.2	8.9	8.5	8.2	7.9
4	18.5	17.4	16.5	15.6	14.8	14.1	13.5	12.9	12.4	11.9	11.4	11.0	10.6
5	23.5	22.1	20.8	19.7	18.8	17.9	17.0	16.3	15.6	15.0	14.4	13.9	13.4
6	28.6	26.9	25.3	24.0	22.8	21.7	20.7	19.7	18.9	18.1	17.4	16.8	16.2
7	33.9	31.8	30.0	28.3	26.9	25.6	24.4	23.3	22.3	21.4	20.5	19.7	19.0
8	39.5	37.0	34.8	32.9	31.1	29.6	28.2	26.9	25.7	24.7	23.7	22.8	21.9
9	45.5	42.5	39.9	37.6	35.5	33.7	32.1	30.6	29.2	28.0	26.9	25.8	24.9
10	51.9	48.3	45.2	42.5	40.1	38.0	36.1	34.4	32.9	31.5	30.2	29.0	27.9
11	59.0	54.5	50.8	47.7	44.9	42.5	40.3	38.4	36.6	35.0	33.6	32.2	31.0
12	67.4	61.6	57.0	53.2	50.0	47.2	44.7	42.5	40.5	38.7	37.0	35.5	34.2
13		70.4	64.1	59.4	55.5	52.2	49.3	46.8	44.5	42.5	40.6	39.0	37.4
14			73.8	66.5	61.6	57.6	54.3	51.3	48.8	46.5	44.4	42.5	40.8
15					68.9	63.7	59.6	56.2	53.2	50.6	48.3	46.2	44.2
16						71.5	65.8	61.6	58.1	55.1	52.4	50.0	47.9
17							74.6	67.9	63.5	59.9	56.8	54.1	51.7
18									70.0	65.3	61.6	58.5	55.7
19										72.3	67.1	63.3	60.1
20												69.0	64.9
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PREDICTED [illegible]

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[illegible]

	-60	-50	-40	-30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					WATER POTENTIAL, NEGATIVE BARS								
1	4	[illegible]	[illegible]	[illegible]	3.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.6	[illegible]
[illegible]	[illegible]	[illegible]	7.8	7.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	11.1	10.6	10.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.9	[illegible]
4	[illegible]	16.8	[illegible]	15.0	14.3	13.6	[illegible]	[illegible]	[illegible]	11.4	11.[illegible]	10.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	20.0	19.0	[illegible]	17.1	[illegible]	[illegible]	[illegible]	[illegible]	13.8	[illegible]	[illegible]
6	27.[illegible]	25.8	24.3	23.0	21.6	[illegible]	19.8	18.9	18.1	17.4	16.7	[illegible]	15.5
7	[illegible]	30.6	[illegible]	27.2	[illegible]	[illegible]	23.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	37.9	35.5	[illegible]	31.5	[illegible]	28.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	43.5	[illegible]	38.1	[illegible]	34.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	46.0	43.1	40.6	38.3	[illegible]	[illegible]	[illegible]	[illegible]	30.1	[illegible]	[illegible]	26.6
11	[illegible]	[illegible]	[illegible]	45.4	[illegible]	40.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	58.2	54.0	50.6	47.5	44.9	[illegible]	[illegible]	[illegible]	36.9	[illegible]	[illegible]	[illegible]
13	[illegible]	65.5	[illegible]	56.1	52.6	49.5	46.9	44.5	[illegible]	40.4	38.7	37.1	[illegible]
14	[illegible]	[illegible]	[illegible]	62.3	58.0	54.5	51.4	48.7	46.3	[illegible]	42.2	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	64.2	[illegible]	56.2	53.1	50.4	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66.0	[illegible]	[illegible]	[illegible]	[illegible]	49.6	47.4	45.4
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	74.5	67.8	63.2	59.5	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.0	[illegible]	55.0	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71.3	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60.6
M [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I 23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R 26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F 4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A 41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D 4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I 4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N 46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
G 4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 11.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	[illegible]	[illegible]	[illegible]	[illegible]	3.3	3.2	3.0	2.9	2.8	2.7	2.6	2.5	2.4
2	[illegible]	7.9	7.5	7.1	6.7	6.4	6.1	5.9	5.6	5.4	5.2	5.0	4.8
3	[illegible]	12.0	11.3	10.7	10.2	9.7	9.3	8.9	8.5	8.2	7.9	7.6	7.3
4	[illegible]	16.2	15.3	14.5	13.7	13.1	12.5	11.9	11.4	11.0	10.5	10.1	9.8
5	[illegible]	20.5	19.3	18.3	17.3	16.5	15.7	[illegible]	14.4	13.8	13.3	12.8	12.3
6	[illegible]	24.9	23.4	22.1	21.0	[illegible]	19.0	18.2	17.4	16.7	16.0	15.4	14.9
7	31.3	29.4	27.7	26.1	24.8	23.5	22.4	21.4	20.5	19.6	18.8	18.1	17.5
8	[illegible]	34.1	32.0	30.2	28.6	27.2	25.9	24.7	23.6	22.6	21.7	20.9	20.1
9	41.7	[illegible]	36.6	34.4	32.6	30.9	29.4	28.0	26.8	25.7	24.6	23.7	22.8
10	47.3	44.1	41.3	38.8	[illegible]	34.8	33.0	31.5	30.1	28.8	27.6	26.5	25.5
11	[illegible]	[illegible]	46.2	43.4	40.9	38.7	36.8	35.0	33.4	32.0	30.6	29.4	28.3
12	[illegible]	55.3	51.5	48.2	[illegible]	42.9	40.6	38.7	36.9	35.2	33.7	32.4	31.1
13	[illegible]	61.8	57.2	53.3	50.0	47.2	44.7	[illegible]	[illegible]	38.6	36.9	35.4	34.0
14		69.6	63.5	[illegible]	55.0	51.7	48.9	[illegible]	44.1	42.1	40.2	38.5	37.0
15			71.4	65.1	60.5	[illegible]	53.3	50.5	47.9	45.7	[illegible]	41.7	40.0
16				73.3	66.7	62.0	58.1	54.8	[illegible]	49.4	47.1	45.1	43.2
17					75.6	68.2	63.4	59.5	[illegible]	53.4	50.8	48.5	46.4
18							69.6	64.7	[illegible]	57.5	54.7	52.1	49.8
19								71.1	[illegible]	62.1	58.8	55.9	53.4
20									72.5	67.3	63.3	60.0	57.1
21										74.1	68.5	64.5	61.1
22												69.7	65.6
23													70.8
24													
25													
26													
27													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 13.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	-5	-4[illegible]	-3[illegible]	-2[illegible]	-10	0	+10	+20	+30	+40	+50	+60
1	[illegible].9	3.7	3.[illegible]	[illegible]	[illegible].1	[illegible].0	2.8	2.7	2.6	2.5	2.4	2.3	2.2
2	7.[illegible]	[illegible].4	[illegible].0	6.[illegible]	[illegible].3	6.0	[illegible].7	5.5	5.2	5.0	4.8	4.7	4.5
3	12.0	11.[illegible]	1[illegible].[illegible]	1[illegible].0	[illegible].5	9.1	[illegible].7	8.3	7.9	7.6	7.3	7.0	6.8
4	[illegible].1	15.1	1[illegible].3	13.[illegible]	12.8	12.2	11.6	11.1	10.6	10.2	9.8	9.4	9.1
5	[illegible].4	19.1	[illegible]	[illegible]	1[illegible].1	15.3	14.6	14.0	13.4	12.8	12.3	11.8	11.4
6	[illegible]	[illegible]	21.[illegible]	20.[illegible]	19.5	18.6	17.7	16.9	16.2	15.5	14.9	14.3	13.8
7	29.2	27.4	[illegible].7	24.[illegible]	2[illegible].0	21.8	20.8	19.9	19.0	18.2	17.5	16.8	16.2
8	[illegible]	[illegible].7	29.[illegible]	[illegible].1	[illegible].5	25.2	[illegible]	22.9	21.9	20.9	20.1	19.3	18.6
9	38.7	[illegible].1	33.9	31.[illegible]	[illegible].2	28.6	27.2	25.9	24.8	23.7	22.8	21.9	21.0
10	43.7	40.7	[illegible]	[illegible]	[illegible].9	32.1	30.5	29.1	27.8	26.6	25.5	24.5	23.5
11	49.[illegible]	4[illegible].5	42.6	40.0	37.7	35.7	33.9	32.3	30.8	29.5	28.2	27.1	26.1
12	54.[illegible]	[illegible].6	47.[illegible]	44.3	41.7	39.4	37.4	35.6	33.9	32.4	31.1	29.8	28.6
13	[illegible]	[illegible].1	52.1	48.7	45.8	43.3	41.0	39.0	37.1	35.5	33.9	32.6	31.3
14	68.[illegible]	[illegible]	[illegible]	[illegible]	[illegible].1	47.3	44.7	42.4	40.4	38.6	36.9	35.4	33.9
15		69.[illegible]	[illegible].1	[illegible].5	54.7	51.4	48.6	46.0	43.8	41.7	39.9	38.2	36.7
16			69.9	64.1	59.6	55.9	52.6	49.8	47.3	45.0	43.0	41.2	39.5
17				70.[illegible]	[illegible].1	60.6	[illegible].9	53.7	50.9	48.4	46.2	44.2	42.3
18					71.6	65.9	[illegible]	57.9	54.8	52.0	49.5	47.3	45.3
19						72.4	66.7	62.4	58.8	55.7	53.0	50.5	48.3
20							73.1	67.5	63.2	59.7	56.6	53.9	51.5
M 21								73.9	68.2	64.0	60.5	57.5	54.8
22									74.6	68.9	64.7	61.3	58.3
I 23										75.4	69.5	65.4	62.0
24											76.2	70.1	66.0
C 25													70.7
R 26													
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O 28													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS

	-60	-50	-40	-30		-10		+10				
1		3.6	3.4									
	7			6.4								
3	11.6	10.9	10.3							7.4	7.1	
4	7	14.7	13.8	13.1	12.4	11.8	11.2	10.7				
	6	18.5	17.5						9			11.4
6	24.		21.1	20.0	18.9		17.1				14.4	
		26.5	24.9	23.5						17.6	16.9	
		30.6		27.1	25.7					20.2	19.4	17
	37.	34.9	32.7		29.1							20
	4		36.8	34.6								7
	47.2		41.0		36.4							1
12	52.	48.7	45.4	42.6	40.1			34.3		31.2		
		53.8			44.1	41.6			7		32.7	
14			54.9	51.3	48.1	45.4	42.9		36			34.0
15		65.3	60.2	55.9	52.4			44.2	0	40.1		
1		72.8	66.0	61.0	56.9		51.4	47.7				
17				66.7			54.4		48	46.4		
				73.7						49.7	47.4	48
19					74.1	67.8			55			
						74.5						51.5
M 21								60.7				54.7 52
22												
I									75			
R 26												76.5 70
27												
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 15.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60

WATER POTENTIAL, NEGATIVE BARS

1	3.[illegible]	[illegible]	[illegible]	[illegible].1	[illegible]	[illegible]	2.7	2.6	2.5	2.4	2.3	2.2	2.1
2	7.5	7.[illegible]	[illegible]	[illegible].3	5.9	5.7	5.4	5.1	4.9	4.7	4.5	4.4	4.2
3	11.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.1	7.8	7.4	7.1	6.8	6.6	6.3
4	[illegible]	14.3	13.[illegible]	1[illegible].7	12.0	11.4	10.9	10.4	10.0	9.5	9.2	8.8	8.5
5	19.2	18.0	[illegible]	[illegible]	[illegible]	14.4	13.7	13.1	12.5	12.0	11.5	11.1	10.7
6	[illegible].3	21.8	[illegible]	1[illegible].4	18.3	17.4	16.6	15.8	15.1	14.5	13.9	13.4	12.9
7	[illegible]	[illegible].7	24.[illegible]	[illegible].3	[illegible].6	[illegible].5	19.5	18.6	17.7	17.0	16.3	15.7	15.1
8	[illegible]	[illegible].7	27.9	[illegible].3	24.8	23.[illegible]	22.4	21.4	20.4	19.5	18.7	18.0	17.3
9	[illegible].2	33.8	[illegible].7	[illegible]	[illegible]	[illegible].7	25.4	24.2	23.1	22.1	21.2	20.4	19.6
10	4[illegible].8	38.[illegible]	[illegible]	[illegible].5	31.6	[illegible]	28.5	27.1	25.9	24.8	23.7	22.8	21.9
11	45.6	42.4	[illegible].6	37.3	35.1	[illegible].3	31.6	30.1	28.7	27.4	26.3	25.2	24.2
12	[illegible].6	46.9	43.8	41.1	[illegible].7	[illegible]	34.8	33.1	31.5	30.1	28.9	27.7	26.6
13	55.9	51.7	48.2	45.1	4[illegible].5	4[illegible].1	38.0	36.1	34.4	32.9	31.5	30.2	29.0
14	61.[illegible]	[illegible]	[illegible].8	49.3	46.3	43.7	41.4	39.3	37.4	35.7	34.2	32.8	31.5
15	[illegible].3	62.[illegible]	57.6	53.7	[illegible]	47.4	44.8	42.5	40.5	38.6	36.9	35.4	33.9
16		68.6	62.[illegible]	[illegible]	[illegible]	51.[illegible]	48.4	45.8	43.6	41.5	39.7	38.0	36.5
17			66.9	63.4	59.0	[illegible]	52.1	49.3	46.8	44.6	42.6	40.7	39.1
18				69.1	[illegible]	59.6	56.0	52.9	50.1	47.7	45.5	43.5	41.7
19					69.3	64.3	60.1	56.7	53.6	[illegible]	48.5	46.4	44.4
20					77.1	[illegible]	64.6	60.6	57.3	54.3	51.7	49.3	47.2
M 21						[illegible]	69.7	65.0	61.1	57.8	54.9	52.3	50.0
22							76.7	69.9	65.3	61.6	58.3	55.5	53.0
I 23								76.5	70.0	65.6	62.0	58.8	56.0
24									76.3	70.2	[illegible]	62.3	59.3
C [illegible]										76.2	70.3	66.1	62.7
R 26											76.1	70.4	66.4
27												76.0	70.5
[illegible]													75.9
[illegible]													
V [illegible]													
O 31													
[illegible]													
L [illegible]													
34													
T [illegible]													
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37													
R [illegible]													
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E 4[illegible]													
A 41													
42													
T 43													
44													
I 45													
N 46													
47													
G 48													
49													
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67													
[illegible]													
69													

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 16.0

	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.1	[illegible]	[illegible]	[illegible]	[illegible]
	2	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	11	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.9	7.5	7.2	[illegible]	[illegible]	[illegible]	6.4	[illegible]	[illegible]
	4	14.8	13.9	13	[illegible]	4	11.7	11	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	5	[illegible]	[illegible]	[illegible]	5	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.6	[illegible]	[illegible]	10.7	[illegible]	[illegible]
	6	22.7	21.2	[illegible]	0	18	[illegible]	[illegible]	9	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	7	[illegible]	[illegible]	[illegible]	5	22	[illegible]	[illegible]	9	[illegible]	9	[illegible]	18.0	17.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.7	19.6	18.9	18.2	17.4	16.8	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	7	28	[illegible]	[illegible]	[illegible]	[illegible]	24	[illegible]	23.5	22.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.6	[illegible]	26.2	25.1	24.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	11	44..	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.5	25.4	24.4	[illegible]	[illegible]	[illegible]
	12	46	[illegible]	4	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32.0	30.5	[illegible]	[illegible]	26.8	[illegible]	[illegible]	[illegible]
	13	[illegible]	[illegible]	[illegible]	5	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	14	[illegible]	4	7	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4
	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	16	72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	44.2	42.0	40.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	18	[illegible]	[illegible]	[illegible]	71	8	65	[illegible]	[illegible]	1	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40.1	[illegible]
	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71	[illegible]	[illegible]	[illegible]	57	6	[illegible]	[illegible]	[illegible]	[illegible]	44.6	42.7	[illegible]	[illegible]
	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]	[illegible]	47.4	[illegible]	[illegible]	[illegible]
M	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71	2	[illegible]	[illegible]	61.9	56.4	[illegible]	53.6	50.2	[illegible]	[illegible]	[illegible]
	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56.6	[illegible]
C	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.5	70.6	66.5	[illegible]	[illegible]	[illegible]
	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75.6	[illegible]	[illegible]	[illegible]
	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
T	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
G	48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PREDICTED WATER POTENTIAL

[illegible] TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 17.0

[illegible]

	-60	-50	-40	-30	-20	-10	0	+10	[illegible]	[illegible]	[illegible]	+50	+60
	WATER POTENTIAL, NEGATIVE BARS												
[illegible]	[illegible]	[illegible]	3.1	3.0	[illegible]	2.7	2.5	2.4	2.3	2.2	2.1	2.1	2.0
[illegible]	7.1	[illegible]	[illegible]	[illegible]	[illegible]	5.4	5.1	4.9	4.7	4.5	4.3	4.1	4.0
[illegible]	10.[illegible]	10.1	9.5	[illegible]	8.5	8.1	7.7	[illegible]	7.0	6.7	6.5	[illegible]	6.0
4	[illegible]	13.6	12.8	12.0	11.4	10.8	10.3	9.8	9.4	9.0	[illegible]	[illegible]	8.0
[illegible]	[illegible]	17.1	16.1	15.2	14.3	13.6	13.0	12.4	11.8	11.3	[illegible]	10.4	10.0
[illegible]	22.1	20.7	19.4	[illegible]	17.3	16.4	15.6	14.9	14.3	13.6	13.1	12.6	12.1
7	[illegible]	24.3	22.8	21.5	20.4	19.3	[illegible]	17.5	16.7	16.0	15.3	14.7	14.2
8	[illegible]	[illegible]	26.3	24.8	23.4	22.2	21.1	[illegible]	19.2	18.4	17.6	16.9	16.3
9	[illegible]	31.9	29.9	28.1	26.6	25.2	[illegible]	22.8	21.7	20.8	19.9	19.1	18.4
[illegible]	[illegible]	35.8	33.5	31.5	29.7	28.2	26.7	25.5	24.3	23.2	22.3	21.4	20.5
11	[illegible]	39.8	37.2	35.0	33.0	31.2	29.6	[illegible]	26.9	25.7	24.6	23.6	22.7
12	47.4	[illegible]	41.1	38.5	36.3	34.3	32.6	31.0	29.5	28.2	27.0	25.9	24.9
13	[illegible]	[illegible]	[illegible]	42.2	39.7	37.5	35.6	33.8	32.2	30.8	29.5	28.2	27.1
14	[illegible]	52.8	49.1	46.0	43.2	40.8	38.6	36.7	35.0	33.4	31.9	30.6	29.4
15	[illegible]	57.6	53.4	49.9	[illegible]	44.1	41.8	39.6	37.7	36.0	34.4	33.0	31.7
[illegible]	[illegible]	62.7	58.0	54.0	50.6	47.6	45.0	42.7	40.6	38.7	37.0	35.4	34.0
17	[illegible]	68.5	62.8	58.3	[illegible]	51.2	[illegible]	45.8	43.5	41.4	39.6	37.9	36.3
18		75.8	68.2	62.9	58.6	54.9	51.7	[illegible]	[illegible]	44.2	42.2	40.4	38.7
19			74.8	68.0	62.9	58.8	55.3	52.2	49.5	47.1	45.0	43.0	41.2
20				74.1	67.8	63.0	59.1	55.7	52.7	50.1	47.7	45.6	43.7
M 21					73.4	67.6	63.0	59.3	56.0	53.1	50.6	48.3	46.2
22						72.9	67.4	63.1	59.5	56.3	53.6	51.1	48.8
I 23							72.4	67.2	63.1	59.7	56.6	53.9	51.5
24								71.9	67.1	63.2	59.8	56.9	54.3
C 25									71.6	67.0	63.2	60.0	57.1
P 26									77.8	71.2	66.8	63.2	60.1
27										76.7	70.9	66.7	63.3
[illegible] 28											75.9	70.6	66.6
29												75.3	70.3
V 30													74.7
C 31													
32													
L 33													
34													
T 35													
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R 38													
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F 40													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 19.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	[illegible]	[illegible]	[illegible]	2.6	2.7	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.9
2	[illegible]	[illegible]	6.0	5.7	5.4	5.1	4.9	4.6	4.4	4.2	4.1	3.9	3.8
3	[illegible]	9.7	9.1	8.6	8.1	7.7	7.3	7.0	6.7	6.4	6.1	5.9	5.7
4	13.9	[illegible]	[illegible]	11.5	10.9	10.3	9.8	9.3	8.9	8.5	8.2	7.9	7.6
5	17.5	16.3	15.3	14.4	13.7	12.9	12.3	11.7	11.2	10.7	10.3	9.9	9.5
6	21.1	19.7	18.5	17.4	16.5	15.6	14.8	14.1	13.5	12.9	12.4	11.9	11.4
7	24.8	23.2	21.7	20.5	19.3	18.3	17.4	16.6	15.8	15.1	14.5	13.9	13.4
8	28.6	26.7	25.0	23.5	22.2	21.1	20.0	19.1	18.2	17.4	16.7	16.0	15.4
9	32.5	30.3	28.4	26.7	25.2	23.8	22.6	21.5	20.6	19.7	18.8	18.1	17.4
10	36.5	34.0	31.8	29.9	28.2	26.7	25.3	24.1	23.0	21.9	21.0	20.2	19.4
11	40.6	37.7	35.3	33.1	31.2	29.5	28.0	26.6	25.4	24.3	23.2	22.3	21.4
12	44.8	41.6	38.8	36.4	34.3	32.4	30.7	29.2	27.9	26.6	25.5	24.4	23.5
13	49.1	45.5	42.5	39.8	37.4	35.4	33.5	31.9	30.4	29.0	27.7	26.6	25.5
14	53.7	49.6	46.2	43.1	40.7	38.4	36.4	34.5	32.9	31.4	30.0	28.8	27.6
15	58.4	53.9	50.1	46.8	44.0	41.5	39.2	37.3	35.5	33.8	32.4	31.0	29.8
16	63.6	58.4	54.1	50.5	47.4	44.6	42.2	40.0	38.1	36.3	34.7	33.3	31.9
17	69.3	63.2	58.3	54.3	50.9	47.9	45.2	42.9	40.7	38.8	37.1	35.5	34.1
18	76.4	68.5	62.8	58.3	54.5	51.2	48.3	45.7	43.5	41.4	39.5	37.8	36.3
19		74.7	67.7	62.5	58.3	54.6	51.5	48.7	46.2	44.0	42.0	40.2	38.5
20			73.4	67.1	62.3	58.2	54.8	51.8	49.1	46.7	44.5	42.6	40.8
M 21				72.3	66.6	62.0	58.2	54.9	52.0	49.4	47.1	45.0	43.1
22					71.4	66.1	61.8	58.2	55.0	52.2	49.7	47.5	45.5
I 23					77.7	70.6	65.6	61.6	58.2	55.1	52.5	50.0	47.9
24						76.0	69.8	65.3	61.4	58.1	55.2	52.6	50.3
C 25							74.7	69.2	64.9	61.3	58.1	55.3	52.8
R 26								73.7	68.6	64.6	61.1	58.1	55.4
27									72.8	68.1	64.3	61.0	58.1
O 28										72.0	67.6	64.0	60.9
29										76.9	71.3	67.2	63.8
V 30											75.7	70.7	66.8
O 31												74.8	70.2
32													73.9
L 33													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE ---

WATER POTENTIAL, NE

		-60	-50	-40	-30	-20	-10							
	1	[illegible]	3.1	2.9	[illegible]	2.6	[illegible]	2.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.8
	2	[illegible]	6.3	5.9	[illegible]	[illegible]	5.0	4.7	4.5	[illegible]	4.1	[illegible]	[illegible]	[illegible]
	[illegible]	10.1	[illegible]	[illegible]	3.4	7.9	[illegible]	7.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	4	13.6	12.7	11.9	[illegible]	[illegible]	10.1	9.6	9.1	[illegible]	8.3	[illegible]	7.7	7.4
	5	17.1	16.0	15.0	14.1	13.3	[illegible]	12.0	11.4	10.9	[illegible]	[illegible]	[illegible]	[illegible]
	6	20.7	19.3	18.1	[illegible]	16.1	15.2	14.5	13.8	13.2	[illegible]	12.1	[illegible]	11.2
	7	24.3	22.7	21.2	20.0	[illegible]	17.9	17.0	16.2	15.4	14.8	14.1	13.6	13.1
	8	28.0	26.1	24.4	23.0	21.7	20.5	19.5	18.6	17.7	[illegible]	16.2	[illegible]	15.0
	9	31.8	29.6	27.7	26.0	24.6	[illegible]	22.1	21.0	20.0	19.1	18.3	17.6	16.9
	10	35.6	33.1	31.0	29.1	[illegible]	26.0	24.6	23.4	22.4	21.4	[illegible]	19.6	18.9
	11	39.6	36.8	34.4	[illegible]	[illegible]	28.7	27.3	25.9	24.7	23.6	[illegible]	21.7	20.8
	12	43.6	40.5	[illegible]	[illegible]	33.4	31.6	29.9	[illegible]	27.1	25.9	24.8	[illegible]	[illegible]
	13	47.8	44.[illegible]	41.3	38.7	36.4	34.4	[illegible]	31.0	[illegible]	28.2	27.0	[illegible]	24.8
	14	52.1	48.2	44.9	42.1	39.5	37.3	35.3	33.6	32.0	[illegible]	29.2	28.0	[illegible]
	15	56.7	52.3	48.6	45.5	42.7	40.3	38.1	36.2	34.5	32.9	[illegible]	30.1	28.9
	16	61.5	56.6	52.5	[illegible]	46.0	43.3	41.0	[illegible]	37.0	35.3	33.7	32.3	31.0
	17	66.7	61.1	[illegible]	52.6	49.3	46.4	43.9	41.6	39.5	37.7	[illegible]	34.5	33.1
	18	72.6	65.9	60.7	56.4	52.8	49.6	46.8	44.4	42.1	40.2	38.4	36.7	35.2
	19		71.3	65.2	60.4	56.3	52.9	[illegible]	47.2	44.8	42.7	40.7	39.0	37.3
	20			70.1	[illegible]	60.1	[illegible]	[illegible]	50.1	47.5	45.2	43.1	[illegible]	[illegible]
M	21			76.1	[illegible]	64.0	59.8	56.2	53.1	50.3	47.8	45.6	43.6	41.7
	22				74.4	68.3	[illegible]	59.6	[illegible]	53.2	50.5	[illegible]	[illegible]	[illegible]
I	23					73.1	67.5	63.1	[illegible]	56.1	[illegible]	50.7	48.4	46
	24						71.9	66.8	62.7	59.1	56.1	[illegible]	50.6	48.6
C	25						77.6	70.9	66.2	62.3	[illegible]	56.0	53.4	51.0
R	26							75.8	70.1	65.7	[illegible]	58.8	[illegible]	53.4
	27								74.5	[illegible]	65.2	61.7	58.7	55.9
O	28									73.4		64.6	[illegible]	58.5
	29										72.4	68.0	64.4	[illegible]
V	30											71.5	67.4	64.0
C	31											[illegible]	70.8	[illegible]
	32												74.5	70.1
L	33													73.6
	34													78.1
T	35													
	36													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 21.0

[illegible]

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.2	2.1	2.0	1.9	1.9	1.8
[illegible]	6.6	6.2	5.8	5.4	5.1	4.9	4.6	4.4	4.2	4.0	3.9	3.7	3.6
3	9.9	9.3	8.7	8.2	7.8	7.3	7.0	6.7	6.4	6.1	5.8	5.6	5.4
4	13.3	12.4	11.7	11.0	10.4	9.8	9.4	8.9	8.5	8.1	7.8	7.5	7.2
5	16.8	15.6	14.7	13.8	13.0	12.4	11.7	11.2	10.7	10.2	9.8	9.4	9.0
[illegible]	[illegible]	[illegible]	[illegible]	16.7	15.7	[illegible]	14.2	13.5	12.9	12.3	11.8	11.3	10.9
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.6	15.8	15.1	14.4	13.8	13.2	12.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.2	20.1	19.0	18.1	17.3	16.5	15.8	15.2	14.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.5	20.5	19.5	18.7	17.9	17.2	16.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.0	22.9	21.8	20.8	19.9	19.1	18.4
[illegible]	38.6	[illegible]	[illegible]	31.5	29.7	[illegible]	26.6	[illegible]	24.1	23.0	22.0	21.1	20.3
[illegible]	[illegible]	[illegible]	36.9	34.6	[illegible]	[illegible]	29.2	27.7	26.4	25.2	24.1	23.1	22.2
13	[illegible]	[illegible]	[illegible]	[illegible]	35.5	33.5	31.8	30.2	28.7	27.4	26.3	25.2	24.2
14	[illegible]	47.0	43.7	40.9	38.5	36.3	34.4	32.7	31.1	29.7	28.4	27.2	26.1
[illegible]	[illegible]	[illegible]	47.3	44.2	[illegible]	[illegible]	37.1	35.2	33.5	32.0	30.6	29.3	28.1
[illegible]	[illegible]	[illegible]	[illegible]	47.6	44.7	42.1	39.8	37.8	35.9	34.3	32.8	31.4	30.1
17	64.5	59.2	[illegible]	[illegible]	[illegible]	[illegible]	42.6	40.4	38.4	36.6	35.0	33.5	32.1
[illegible]	[illegible]	[illegible]	[illegible]	54.7	51.2	48.1	45.4	43.1	40.9	39.0	37.2	35.7	34.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54.6	51.3	48.3	45.8	43.5	41.4	39.5	37.8	36.3
20		[illegible]	67.4	[illegible]	58.1	54.5	51.3	[illegible]	46.1	43.9	41.9	40.0	38.4
[illegible]			72.4	[illegible]	61.8	[illegible]	54.4	51.4	48.7	46.4	44.2	42.3	40.5
22				71.1	65.7	[illegible]	57.5	54.3	51.4	48.9	46.6	44.5	42.6
[illegible]				[illegible]	69.9	64.9	60.8	57.3	54.2	51.5	49.1	46.8	44.8
[illegible]					74.7	[illegible]	64.3	60.4	57.1	54.2	51.5	49.2	47.1
[illegible]						[illegible]	68.0	63.7	60.1	56.9	54.1	51.6	49.3
26							72.0	67.2	63.2	59.7	56.7	54.1	51.6
[illegible]							76.8	70.9	66.4	62.7	59.4	56.6	54.0
[illegible]								75.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									73.9	69.1	65.2	61.9	58.9
[illegible]										72.7	68.3	64.7	61.5
[illegible]										77.1	71.7	67.6	64.2
[illegible]											75.6	70.8	67.0
[illegible]												74.3	70.0
34													73.3
[illegible]													77.2
42													
44													
46													
48													
55													
58													
60													
61													

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 23.0

OFFSET FROM ZERO IN MICROVOLTS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
							WATER POTENTIAL, NEGATIVE BARS							
	1	5.2	[illegible]	2.8	[illegible]	2.5	2.3	2.2	2.1	2.0	1.9	1.8	1.8	1.7
	2	[illegible]	[illegible]	[illegible]	[illegible]	4.9	4.7	4.4	4.2	4.0	3.9	3.7	3.6	3.4
	3	[illegible]	[illegible]	8.4	7.9	7.4	7.0	6.7	6.4	6.1	5.8	5.6	5.3	5.1
	4	[illegible]	12.0	11.2	[illegible]	10.0	9.4	8.9	8.5	8.1	7.8	7.4	7.1	6.9
	5	[illegible]	15.0	14.1	13.2	12.5	11.8	11.2	10.7	10.2	9.7	9.3	9.0	8.6
	6	19.5	18.1	17.0	16.0	15.1	14.3	13.5	12.9	12.3	11.7	11.2	10.8	10.4
	7	22.9	21.3	19.9	18.7	17.6	16.7	15.8	15.1	14.4	13.7	13.2	12.6	12.1
	8	[illegible]	24.5	22.9	21.5	20.3	19.2	18.2	17.3	16.5	[illegible]	15.1	14.5	13.9
	9	[illegible]	27.7	25.9	24.3	22.9	21.7	20.5	19.5	18.6	17.8	17.0	16.3	15.7
	10	[illegible]	31.0	28.9	27.1	25.6	24.2	22.9	21.8	20.8	19.8	19.0	18.2	17.5
	11	36.9	34.3	32.0	30.0	28.3	26.7	25.3	24.1	22.9	21.9	21.0	20.1	19.3
	12	40.6	37.7	35.2	33.0	31.0	29.3	27.7	26.4	25.1	24.0	22.9	22.0	21.1
	13	44.4	41.1	38.3	35.9	33.8	31.9	30.2	28.7	27.3	26.1	24.9	23.9	22.9
	14	[illegible]	44.7	41.6	38.9	36.6	34.5	32.7	31.0	29.6	28.2	27.0	25.8	24.8
	15	[illegible]	48.3	44.9	42.0	39.5	37.2	35.2	33.4	31.8	30.3	29.0	27.8	26.7
	16	[illegible]	52.0	48.3	45.1	42.4	39.9	37.8	35.8	34.1	32.5	31.1	29.8	28.5
	17	60.7	55.8	51.8	48.3	45.3	42.7	40.4	38.3	36.4	34.7	33.1	31.7	30.4
	18	[illegible]	59.8	55.4	51.6	48.4	45.5	43.0	40.7	38.7	36.9	35.3	33.7	32.4
	19	[illegible]	64.1	59.1	55.0	51.5	48.4	45.7	43.3	41.1	39.1	37.4	35.8	34.3
	20	76.[illegible]	68.6	63.0	58.5	54.6	51.3	48.4	45.8	43.5	41.4	39.5	37.8	36.2
M	21		73.6	67.2	62.1	57.9	54.3	51.2	48.4	45.9	43.7	41.7	39.9	38.2
	22			71.7	66.0	61.3	57.4	54.0	51.1	48.4	46.1	43.9	42.0	40.2
I	23			77.0	70.1	64.9	60.6	57.0	53.8	51.0	48.4	46.2	44.1	42.2
	24				74.7	68.7	64.0	60.0	56.6	53.5	50.9	48.4	46.3	44.3
C	25					72.9	67.5	63.1	59.4	56.2	53.3	50.8	48.5	46.4
R	26					77.9	71.3	66.4	62.4	58.9	55.9	53.1	50.7	48.5
	27						75.6	70.0	65.5	61.7	58.5	55.6	53.0	50.6
O	28							73.8	68.8	64.7	61.1	58.0	55.3	52.8
	29							78.8	72.3	67.7	63.9	60.6	57.7	55.0
V	30								76.4	71.0	66.8	63.2	60.1	57.3
O	31									74.7	69.9	66.0	62.6	59.6
	32										73.2	68.9	65.2	62.0
L	33										77.1	71.9	67.9	64.5
	34											75.4	70.8	67.1
T	35												74.0	69.8
	36												77.7	72.7
	37													76.0
R	38													
	39													
E	40													
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PSYCHROMETER TEMPERATURE, CENTIGRADE --- 24.0

1		1	9	2.7			2.4				2.1	2.0				
2			8	5.4				4.6								
		4	8													
4			7	11.0	10.3	9.7							7.6			
			7	13.8	13.0			11.6					9.			
			8	16.6		14.7	13.9									10.1
7		4			18.3		16.3			14.7				12.9		
	25.				21.0		18.7								14.1	13.6
9			1							19.1		17.4				15.3
	32.6									21.3						17.1
11		1					26.1				22.4	21.4				
12	7	7	36.8	34.4		30.3	28.6	27.1		25.7	24.5			22.4		20.6
13			40 2	37.5	35.1		31.1			28.0	26.7	25.4				
14		1	43.6	40.6	38.0			1.9								24.2
15			47 1	43.8		38.5	36.3									26.0
16			7	47		41.3						31.7				
17			54.4	50.4	47.1	44.2	41.6									29.7
18			2	53.9	50.2	47.1	44.3				37.7					
19			62.2	57.4		50.1	47.1	44.4		4.1						.4
20			4	61.1	56.8					44.6						
M										47.1				40.6		
			1	69.1		59.5				49.6	47.1	44.8			1 .	
I 23				73.7		62.8	58.8				49.5					
24						66.3				54.9						
C 25					76.5	70.1	65.2	61.1		57.6					47.1	
R							68.7				57.1				49.	
27							72.4	67.4		63.3	59.7					
O							76.7	70.9								
29								74.7								53.3
V												64.4	61.1	58.1		
											71.5	67.3	62.6	60.5		57.7
												70.2				
I 33																
34												77.1		68.1		64.6
T																
R																75.6
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D 43																
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 23.0

OFFSET FROM ZERO IN MICROVOLTS

		[illegible]	[illegible]	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
		WATER POTENTIAL, NEGATIVE BARS												
	1	[illegible]	2.9	2.8	[illegible]	2.5	2.3	2.2	2.1	2.0	1.9	1.8	1.8	1.7
	2	[illegible]	5.9	[illegible]	5.2	4.9	4.7	4.4	4.2	4.0	3.9	3.7	3.6	3.4
	3	[illegible]	8.9	8.4	7.9	7.4	7.0	6.7	6.4	6.1	5.8	5.6	5.3	5.1
	4	[illegible]	12.0	11.2	10.5	10.0	9.4	8.9	8.5	8.1	7.8	7.4	7.1	6.9
	5	16.1	[illegible]	14.1	13.2	12.5	11.8	11.2	10.7	10.2	9.7	9.3	9.0	8.6
	6	[illegible]	18.1	17.0	16.0	15.1	14.3	[illegible]	12.9	12.3	11.7	11.2	10.8	10.4
	7	22.9	21.3	19.9	18.7	17.6	16.7	15.8	15.1	14.4	13.7	13.2	12.6	12.1
	8	[illegible]	24.5	22.9	21.5	20.3	19.2	18.2	17.3	16.5	15.8	15.1	14.5	13.9
	9	[illegible]	27.7	25.9	24.3	22.9	21.7	20.5	19.5	18.6	17.8	17.0	16.3	15.7
	10	[illegible]	31.0	28.9	27.1	25.6	24.2	22.9	21.8	20.8	19.8	19.0	18.2	17.5
	11	36.9	34.3	32.0	30.0	28.3	26.7	25.3	24.1	22.9	21.9	21.0	20.1	19.3
	12	[illegible]	37.7	35.2	33.0	31.0	29.3	27.7	26.4	25.1	24.0	22.9	22.0	21.1
	13	44.4	41.1	38.3	[illegible]	33.8	31.9	30.2	28.7	27.3	26.1	24.9	23.9	22.9
	14	[illegible]	44.7	41.6	38.9	36.6	34.5	32.7	31.0	29.6	28.2	27.0	25.8	24.8
	15	[illegible]	48.3	44.9	42.0	39.5	37.2	35.2	33.4	31.8	30.3	29.0	27.8	26.7
	16	56.4	52.0	48.3	45.1	42.4	39.9	37.8	35.8	34.1	32.5	31.1	29.8	28.5
	17	60.7	55.8	51.8	48.3	45.3	42.7	40.4	38.3	36.4	34.7	33.1	31.7	30.4
	18	[illegible]	59.8	55.4	51.6	48.4	[illegible]	43.0	40.7	38.7	36.9	35.3	33.7	32.4
	19	[illegible]	64.1	59.1	55.0	51.5	48.4	45.7	43.3	41.1	39.1	37.4	35.8	34.3
	20	[illegible]	68.6	63.0	58.5	54.6	51.3	48.4	45.8	43.5	41.4	39.5	37.8	36.2
M	21		73.6	67.2	62.1	57.9	54.3	51.2	48.4	[illegible]	43.7	41.7	39.9	38.2
	22			71.7	66.0	61.3	57.4	54.0	51.1	48.4	46.1	43.9	42.0	40.2
I	23			77.0	70.1	64.9	60.6	57.0	53.8	51.0	48.4	46.2	44.1	42.2
	24				74.7	68.7	64.0	60.0	56.6	53.5	50.9	48.4	46.3	44.3
C	25					72.9	67.5	63.1	59.4	56.2	53.3	50.8	48.5	46.4
R	26					77.9	71.3	66.4	62.4	58.9	55.9	53.1	50.7	48.5
	27						75.6	70.0	65.5	61.7	58.5	55.6	53.0	50.6
O	28							73.8	68.8	64.7	61.1	58.0	55.3	52.8
	29							78.8	72.3	67.7	63.9	60.6	57.7	55.0
V	30								76.4	71.0	66.8	63.2	60.1	57.3
O	31									74.7	69.9	66.0	62.6	59.6
	32										73.2	68.9	65.2	62.0
L	33										77.1	71.9	67.9	64.5
	34											75.4	70.8	67.1
T	35												74.0	69.8
	36												77.7	72.7
	37													76.0
R	38													
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PSYCHROMETER TEMPERATURE, CENTIGRADE

		-60	-50	-40	-30	-20	-10									
	1			2.7										1.6	1.7	1.7
	2		5.8			4.8										
	3		8.8	8.2	7.7		6.9			1.2						
	4		11.7			9.7										
	5		14.7			12.2	11.6	11.0								4
	6	1	17.8			14.7										
	7	22.4	20.9	19.5	18.3	17.3				14.7		13.4				
	8		24.0				18.7	17.8			16.1	15.4	14.7	14.1		
	9	2	27.1			22.4						17.4			15.3	
	10		30.3	28.3	26.5	25.0		22.4				19.4	18.5	17.8	17.1	
	11	1	33.5	31.3	29.3	27.6	26.1				22.4					
	12	7	36.8			30.3	28.6	27.1		25.7	24.5			21.5	20.6	
	13	4	40.2	37.5	35.1	33.0	31.1				26.7					
	14	7.1	43.6	40.6	38.0	35.7	33.7			30.3				25.2		
	15		47.1			38.5				32.6			28.3	27.1	26.0	
	16	54.9	50.7	47.1	44.0	41.3	38.9			34.9		31.7				
	17		54.4	50.4	47.1		41.6									
	18		58.2	53.9	50.2	47.1		41.9		39.7	37.7					
	19	67.	62.2				47.1			42.1						35.4
	20	73	66.4	61.1	56.8	53.1	49.9	47.1			42.					
M	21		70.9			56.2		49.7		47.1			41.6			
	22		76.1	69.1	63.8						47.1		42.7			
I	23			73.7	67.6		58.8	55.3				47.1		42.9		
	24				71.7			58.1		54.9		49.4	47.1			
	25				76.5	70.1	65.2	61.1		57.6						
R	26															
	27						72.4	67.4						51.4	49.1	
	28						76.7				62.5					
	29							74.7		69.5						
V	30										68.3	64.4	61.1			
O	31									76.9	71.5	67.3				
	32											70.2	66.3		59.9	
L	33											73.4				
	34											77.1				
T	35															
	36															
	37													77.5		
R	38															
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 27.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.9	2.7	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.8	1.7	1.6	1.6
	2	6.1	5.5	5.1	4.8	4.5	4.3	4.1	3.9	3.7	3.5	3.4	3.2	3.1
	3	8.9	8.3	7.7	7.3	6.8	6.5	6.1	5.6	5.6	5.3	5.1	4.9	4.7
	4	11.9	11.1	10.3	9.7	9.1	8.7	8.2	7.8	7.4	7.1	6.8	6.5	6.3
	5	14.9	13.9	13.0	12.2	11.5	10.9	10.3	9.8	9.3	8.9	8.5	8.2	7.9
	6	18.1	16.7	15.6	14.7	13.8	13.1	12.4	11.8	11.2	10.7	10.3	9.8	9.4
	7	21.1	19.6	18.3	17.2	16.2	15.3	14.5	13.8	13.1	12.5	12.0	11.5	11.0
	8	24.1	22.5	21.0	19.7	18.6	17.5	16.6	15.8	15.0	14.4	13.7	13.2	12.7
	9	27.4	25.4	23.7	22.3	20.9	19.8	18.8	17.8	17.0	16.2	15.5	14.9	14.3
	10	30.6	28.4	26.5	24.8	23.4	22.1	20.9	19.9	18.9	18.1	17.3	16.5	15.9
	11	33.8	31.4	29.3	27.4	25.8	24.4	23.1	21.9	20.9	19.9	19.0	18.3	17.5
	12	37.1	34.4	32.1	30.1	28.3	26.7	25.3	24.0	22.8	21.8	20.8	20.0	19.2
	13	40.5	37.5	34.9	32.7	30.7	29.0	27.5	26.1	24.8	23.7	22.6	21.7	20.8
	14	43.9	40.6	37.8	35.4	33.3	31.4	29.7	28.2	26.8	25.6	24.4	23.4	22.5
	15	47.4	43.8	40.8	38.1	35.8	33.7	31.9	30.3	28.8	27.5	26.3	25.2	24.1
	16	50.9	47.0	43.7	40.9	38.4	36.2	34.2	32.4	30.8	29.4	28.1	26.9	25.8
	17	54.6	50.3	46.8	43.7	41.0	38.6	36.5	34.6	32.9	31.4	30.0	28.7	27.5
	18	58.3	53.7	49.8	46.5	43.6	41.0	38.8	36.8	35.0	33.3	31.8	30.5	29.2
	19	62.2	57.2	53.0	49.4	46.3	43.5	41.1	39.0	37.0	35.3	33.7	32.2	30.9
	20	66.3	60.5	56.2	52.3	49.0	46.1	43.5	41.2	39.1	37.3	35.6	34.0	32.6
M	21	70.7	64.5	59.5	55.4	51.8	48.6	45.9	43.5	41.3	39.3	37.5	35.9	34.4
	22	75.5	68.4	63.0	58.4	54.6	51.3	48.3	45.7	43.4	41.3	39.4	37.7	36.1
I	23		72.7	66.6	61.6	57.5	53.9	50.8	48.1	45.6	43.4	41.4	39.6	37.9
	24		77.6	70.3	64.9	60.5	56.6	53.3	50.4	47.8	45.5	43.3	41.4	39.7
C	25			74.5	68.4	63.5	59.4	55.9	52.8	50.0	47.6	45.3	43.3	41.5
R	26				72.1	66.7	62.3	58.5	55.2	52.3	49.7	47.3	45.2	43.3
	27				76.2	70.1	65.3	61.2	57.7	54.6	51.9	49.4	47.2	45.1
O	28					73.7	68.4	64.0	60.2	57.0	54.1	51.5	49.1	47.0
	29					77.9	71.7	66.9	62.9	59.4	56.3	53.6	51.1	48.8
V	30						75.3	69.9	65.6	61.8	58.6	55.7	53.1	50.7
O	31							73.1	68.4	64.4	60.9	57.9	55.1	52.7
	32							76.7	71.3	67.0	63.3	60.1	57.2	54.6
I	33								74.5	69.7	65.8	62.4	59.3	56.6
	34								78.2	72.6	68.3	64.7	61.5	58.6
T	35									75.8	71.0	67.1	63.7	60.7
	36										73.9	69.6	66.0	62.8
	37										77.1	72.2	68.3	65.0
R	38											75.1	70.8	67.2
	39											78.4	73.4	69.5
E	40												76.3	71.9
A	41													74.5
	42													77.4
D	43													
	44													
I	45													
N	46													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SE
PSYCHROMETER TEMPERATURE, CENTIGRADE ---

WATER POTENTIAL, NEGATIVE BARS

	4												1.8		1.7			
	5												.6					3.1
	6			7		7.1				6.0				5.2				
	4		10	9	1	9.4	9		5		7.6							6.1
	5	14			12	7 11.9	11				9.6			3.7				
	6	17	6	16	3						11.5			10.5				
	7			19	2 17	16.8			15						11.7			
	8		7			19.3		1	17	1			14.7	14.0				
	9	26		9	23			5			17.4							
	10					24.3					19.4							
	11			7		26.8												
	12		3		31	4				1		23.4					19.5	
	13	39				1 32.0												
	14	9			36	34.6			6		29.0							
	15				8	37.2		9		9								
	16	49		9	7	39.9		4			33.4	31.7	30.1					
	17	53	2	49	1	42.6						35.7						
	18			4							37.8	35.9	34.1					
	19		6	7		48.1			42		40.1							
	20	64	4	1	54	7 51.0	4	7	44		42.4	40.2			34.7			
M	21	68		7		53.9	50				44.7							
	22			4				1	49	9	47.1							
I	23					59.9		9	52	5								
	24		74.			63.0				1						40.4		
	25				71	9		7	57			51.4	48.7					
F	26				1	69.7	64.7				56.9				46.1	44.		
	27					73.4	67		63									
D	28					77.6					62.1		55.4					
	29						74.				64.8	61.0	57.7	54.7		49.7	47.5	
V	30						79	1			67.6	63.6						4
	31									1		66.2	62.4		56.2		51.2	
	32										73.8		64.9				53.1	
	33										77.3			.7	60.5			
	34											74.9	70.1		62.7			
T	35											76.5					58.9	
	36																	
	37													74.0			62.9	
F	38													77.1	72.3			
	39																	
E	40																	
A	41															76.3	71.7	
	42																	
D	43																	
	44																	
I	45																	
N	46																	
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 29.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10		+10	+20	+30	+40	[illegible]	[illegible]
[illegible]	[illegible]	2.6	[illegible]	[illegible]	2.2	2.1	[illegible]	[illegible]	1.8	[illegible]	1.6	1.6	1.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.4	4.1	[illegible]	[illegible]	[illegible]	3.4	3.2	[illegible]	[illegible]
[illegible]	[illegible]	7.9	[illegible]	[illegible]	6.6	[illegible]	5.9	[illegible]	[illegible]	[illegible]	4.9	4.7	4.5
[illegible]	[illegible]	10.6	[illegible]	9.3	[illegible]	[illegible]	[illegible]	[illegible]	7.1	6.8	6.5	6.2	[illegible]
[illegible]	[illegible]	13.3	12.4	11.7	11.0	10.4	[illegible]	[illegible]	[illegible]	8.5	8.1	7.8	7.5
[illegible]	[illegible]	16.0	15.0	14.0	13.2	12.5	11.8	11.3	10.7	10.2	9.8	9.4	9.0
7	[illegible]	18.8	17.5	16.4	15.5	14.6	[illegible]	13.2	12.5	12.0	11.5	11.0	10.5
[illegible]	[illegible]	21.5	20.1	18.8	17.7	[illegible]	15.9	15.1	14.4	13.7	13.1	12.6	12.1
[illegible]	[illegible]	24.3	22.7	21.3	20.0	18.9	17.9	17.0	16.2	15.5	14.8	[illegible]	13.6
[illegible]	[illegible]	27.2	25.3	23.7	[illegible]	21.1	20.0	19.0	18.1	[illegible]	16.5	15.8	15.2
11	[illegible]	30.0	28.0	26.2	24.6	23.3	22.0	20.9	19.9	19.0	18.2	17.4	16.7
[illegible]	[illegible]	32.9	30.6	28.7	27.0	25.5	24.1	22.9	21.8	20.8	19.9	19.0	18.3
[illegible]	[illegible]	35.8	33.3	31.2	29.3	27.7	26.2	24.9	23.7	22.6	21.6	20.7	19.8
[illegible]	[illegible]	38.8	36.1	[illegible]	31.7	29.9	28.3	26.9	25.6	24.4	23.3	22.3	21.4
[illegible]	45.1	41.8	38.8	36.3	34.1	32.2	30.4	28.9	27.5	26.2	25.0	24.0	23.0
[illegible]	[illegible]	44.8	[illegible]	38.9	[illegible]	34.4	32.6	30.9	29.4	28.0	[illegible]	[illegible]	[illegible]
17	[illegible]	47.9	[illegible]	41.6	39.0	36.7	34.7	32.9	31.3	[illegible]	28.5	27.3	26.2
[illegible]	[illegible]	51.0	47.4	44.2	41.5	39.1	36.9	35.0	[illegible]	31.7	30.3	29.0	27.8
[illegible]	[illegible]	54.3	[illegible]	46.9	44.0	41.4	39.1	37.1	35.2	[illegible]	32.1	30.7	29.4
[illegible]	[illegible]	57.6	53.3	[illegible]	46.5	43.8	41.3	39.2	37.2	35.5	33.8	32.4	31.0
[illegible]	[illegible]	61.0	56.4	52.5	49.1	46.2	43.6	41.3	39.2	[illegible]	[illegible]	34.1	32.7
22	[illegible]	64.5	59.5	55.3	51.8	48.6	45.9	43.4	41.2	39.3	37.5	35.8	34.3
[illegible]	[illegible]	68.2	62.8	[illegible]	54.4	51.1	48.2	45.6	[illegible]	41.2	39.3	37.6	36.0
24		72.1	[illegible]	61.3	57.2	53.6	50.5	47.8	45.3	43.1	41.1	39.3	37.7
[illegible]		76.5	69.6	64.4	60.0	56.2	52.9	50.0	47.4	45.1	43.0	41.1	[illegible]
[illegible]			73.4	67.6	62.8	58.8	55.3	52.3	49.5	47.1	44.9	42.9	41.1
[illegible]			[illegible]	71.0	65.8	61.5	57.8	54.5	51.7	49.1	46.8	44.7	42.8
[illegible]				74.7	68.9	64.3	[illegible]	[illegible]	53.8	51.1	48.7	46.5	44.5
29				79.0	72.2	67.1	62.9	59.3	56.1	53.2	50.7	48.4	46.3
[illegible]					75.8	70.1	65.6	61.7	58.3	55.3	52.6	50.2	48.0
[illegible]						73.3	68.3	64.2	60.6	57.4	54.6	52.1	49.8
[illegible]						76.8	71.2	66.8	63.0	59.6	56.7	54.0	51.6
[illegible]							74.3	69.4	65.4	[illegible]	58.7	56.0	[illegible]
[illegible]							77.8	72.3	[illegible]	64.1	60.8	57.9	55.3
[illegible]								75.3	70.5	66.5	63.0	59.9	57.2
36								78.8	73.2	[illegible]	65.2	[illegible]	59.1
[illegible]									76.2	71.4	67.5	64.1	61.0
[illegible]									79.9	74.1	69.8	66.2	63.0
[illegible]										77.1	72.3	68.4	65.1
[illegible]											74.9	70.7	67.2
[illegible]											77.9	73.1	69.3
42												75.7	71.6
[illegible]												78.7	73.9
[illegible]													76.5
45													79.6
47													
63													
64													
66													
68													
70													

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 31.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.7	2.5	2.4	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4
	2	5.4	5.1	4.7	4.4	4.2	3.9	3.7	3.6	3.4	3.2	3.1	3.0	2.9
	3	8.2	7.6	7.1	6.7	6.3	5.9	5.6	5.3	5.1	4.9	4.7	4.5	4.3
	4	10.9	10.2	9.5	9.9	8.4	7.9	7.5	7.1	6.8	6.5	6.2	6.0	5.7
	5	13.7	12.7	11.9	11.2	10.5	9.9	9.4	8.9	8.5	8.1	7.8	7.5	7.2
	6	16.5	15.3	14.3	13.4	12.6	11.9	11.3	10.8	10.2	9.8	9.4	9.0	8.6
	7	19.3	18.0	16.8	15.7	14.8	14.0	13.2	12.6	12.0	11.4	10.9	10.5	10.1
	8	22.1	20.6	19.2	18.0	17.0	16.0	15.2	14.4	13.7	13.1	12.5	12.0	11.5
	9	24.1	23.3	21.7	20.3	19.1	18.1	17.1	16.2	15.5	14.8	14.1	13.5	13.0
	10	26.2	25.9	24.2	22.7	21.3	20.1	19.1	18.1	17.2	16.4	15.7	15.1	14.5
	11	32.9	32.6	26.7	25.0	23.5	22.2	21.0	20.0	19.0	18.1	17.3	16.6	15.9
	12	36.9	31.4	29.2	27.4	25.7	24.3	23.0	21.8	20.8	19.8	19.0	18.2	17.4
	13	36.9	34.2	31.8	29.8	28.0	26.4	25.0	23.7	22.6	21.5	20.6	19.7	18.9
	14	39.9	37.1	34.4	32.2	30.2	28.5	27.0	25.6	24.4	23.2	22.2	21.3	20.4
	15	43.0	39.8	37.0	34.6	32.5	30.7	29.0	27.5	26.2	25.0	23.9	22.8	21.9
	16	46.1	42.7	39.7	37.1	34.8	32.8	31.0	29.4	28.0	26.7	25.5	24.4	23.4
	17	49.3	45.6	42.4	39.6	37.1	35.0	33.1	31.4	29.8	28.4	27.2	26.0	25.0
	18	52.6	48.5	45.1	42.1	39.5	37.2	35.1	33.3	31.7	30.2	28.8	27.6	26.5
	19	55.9	51.5	47.8	44.6	41.8	39.4	37.2	35.3	33.5	32.0	30.5	29.2	28.0
	20	59.3	54.6	50.6	47.2	44.2	41.6	39.3	37.3	35.4	33.7	32.2	30.8	29.6
M	21	62.9	57.8	53.5	49.5	46.7	43.9	41.5	39.3	37.3	35.5	33.9	32.5	31.1
	22	66.5	61.0	56.4	52.5	49.1	46.2	43.6	41.3	39.2	37.3	35.6	34.1	32.7
I	23	70.4	64.3	59.4	55.2	51.6	48.5	45.8	43.3	41.1	39.2	37.4	35.7	34.2
	24	74.6	67.8	62.4	58.0	54.2	50.9	48.0	45.4	43.1	41.0	39.1	37.4	35.8
C	25	78.6	71.5	65.6	60.8	56.8	53.3	50.2	47.5	45.0	42.8	40.9	39.1	37.4
R	26		75.4	68.9	63.7	59.4	55.7	52.4	49.6	47.0	44.7	42.6	40.7	39.0
	27			72.4	66.7	62.1	58.2	54.7	51.7	49.0	46.6	44.4	42.4	40.6
O	28			76.2	69.9	64.9	60.7	57.0	53.9	51.0	48.5	46.2	44.2	42.3
	29				73.2	67.8	63.3	59.4	56.1	53.1	50.4	48.0	45.9	43.9
V	30				76.9	70.8	65.9	61.8	58.3	55.2	52.4	49.9	47.6	45.6
O	31					74.0	68.7	64.3	60.6	57.3	54.4	51.7	49.4	47.2
	32					77.6	71.6	66.9	62.9	59.4	56.4	53.6	51.2	48.9
L	33						74.7	69.5	65.3	61.6	58.4	55.5	53.0	50.6
	34						78.2	72.3	67.8	63.9	60.5	57.5	54.8	52.4
T	35							75.3	70.3	66.2	62.6	59.5	56.6	54.1
	36							78.8	73.0	68.6	64.8	61.5	58.5	55.9
	37								75.9	71.0	67.0	63.5	60.4	57.6
R	38								79.3	73.6	69.3	65.6	62.4	59.5
	39									76.5	71.7	67.8	64.3	61.3
E	40									79.9	74.2	70.0	66.4	63.2
A	41										77.0	72.3	68.5	65.1
	42											74.8	70.6	67.1
D	43											77.5	72.9	69.1
	44												75.3	71.2
I	45												77.9	73.4
N	46													75.7
	47													78.4
G	48													
	49													
	50													
	51													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 33.0

OFFSET FROM ZERO IN MICROVOLTS

POTENTIAL, NEGATIVE BARS

		2.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	1.8	1.7	1.[illegible]	1.5	1.[illegible]	1.4	1.4
	5.[illegible]	4.[illegible]	[illegible]	[illegible]	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]8	7.[illegible]	6.8	6.4	6.0	[illegible]	[illegible]	5.1	4.[illegible]	4.6	4.4	4.3	4.1
4	[illegible]	9.7	9.1	8.5	8.0	7.6	7.2	[illegible]	[illegible]	6.2	5.9	[illegible]	[illegible]
	15.1	12.[illegible]	11.4	10.7	10.9	[illegible]	9.0	[illegible]	[illegible]	[illegible]	[illegible]	7.1	6.8
	[illegible]	[illegible]	13.7	12.8	12.1	11.4	10.8	10.3	9.8	9.3	8.9	[illegible]	[illegible]
	[illegible].5	17.[illegible]	16.0	[illegible]	14.1	13.3	[illegible]	12.0	11.4	10.9	10.4	10.0	9.6
	1.2	[illegible].7	18.4	17.2	16.2	15.3	14.5	13.8	13.1	12.5	12.0	11.5	11.0
	23.9	22.[illegible]	20.7	19.4	18.3	17.2	16.3	15.5	14.8	14.1	13.5	12.9	12.4
10	26.7	24.[illegible]	23.1	21.6	[illegible]	19.2	18.2	17.3	16.5	15.7	15.0	14.4	13.8
11	[illegible]	[illegible]	25.5	23.9	22.5	21.2	20.1	19.1	[illegible]	17.3	16.5	15.9	15.2
12	.3	29.[illegible]	27.9	26.1	24.6	23.2	21.9	20.8	19.8	18.9	18.1	17.3	16.6
[illegible]	35.2	[illegible].6	30.3	[illegible]	26.7	25.2	23.8	22.6	21.5	20.5	19.6	18.8	18.1
[illegible]	38.0	[illegible].2	32.8	30.7	28.8	27.2	25.7	24.4	23.2	22.2	21.2	20.3	19.5
1[illegible]	[illegible].0	37.9	35.3	33.0	31.0	29.2	27.7	26.2	25.0	23.8	22.8	21.8	20.9
16	45.9	40.6	37.8	35.3	[illegible]	31.3	29.6	28.1	26.7	25.5	24.3	23.3	22.3
1[illegible]	46.9	[illegible].4	40.3	37.7	35.4	33.3	31.5	29.9	28.4	27.1	25.9	24.8	23.8
[illegible]	[illegible].0	[illegible]	42.9	40.1	37.6	35.4	33.5	31.8	30.2	28.8	27.5	26.3	25.2
1[illegible]	[illegible].1	[illegible].0	45.5	42.5	39.8	37.5	[illegible]	33.6	32.0	30.5	29.1	27.8	26.7
[illegible]	[illegible]	[illegible].9	48.1	44.9	42.1	39.[illegible]	37.4	35.5	33.7	32.1	30.7	[illegible].4	28.2
N [illegible]	[illegible].5	54.[illegible]	50.8	47.4	44.4	41.[illegible]	39.5	37.4	35.5	33.8	32.3	30.9	29.6
[illegible]	62.9	[illegible].8	53.5	49.9	46.7	43.9	41.5	39.3	37.3	35.6	33.9	32.5	31.1
I 23	66.4	[illegible].8	56.3	52.4	49.0	46.1	43.5	41.[illegible]	39.1	37.3	35.6	34.0	32.6
[illegible]	[illegible].0	[illegible].0	59.1	55.0	51.4	48.3	4[illegible]	[illegible]	41.0	39.0	37.2	35.6	34.1
C [illegible]	[illegible].9	67	62.0	57.6	53.8	50.6	47.7	45.1	42.8	40.8	38.9	37.2	35.6
E 26	[illegible].4	[illegible].7	65.0	[illegible]	56.3	52.8	49.8	47.1	44.7	42.5	40.6	38.8	37.1
[illegible]	[illegible]	[illegible]4.4	68.1	[illegible]	58.8	55.1	51.9	49.1	46.6	[illegible]	42.2	40.4	38.7
[illegible]	[illegible]	[illegible].7	71.4	65.9	61.3	57.5	54.1	51.1	48.5	46.1	43.9	42.0	40.2
[illegible]	[illegible]	[illegible]	74.8	68.8	64.0	59.8	56.3	53.2	50.4	47.9	45.6	43.6	41.8
V [illegible]	[illegible]	[illegible]	[illegible]	71.9	66.7	62.3	58.5	55.2	52.3	49.7	47.4	[illegible]	43.3
O 1	[illegible]	[illegible]	[illegible]	75.2	[illegible]	64.8	60.8	57.4	[illegible]	51.6	49.1	46.9	44.9
32	[illegible]	[illegible]	[illegible]	79.1	72.4	67.4	63.1	[illegible]	56.3	[illegible].4	50.9	48.6	46.5
L	[illegible]	[illegible]	[illegible]	[illegible]	75.6	70.0	65.5	61.7	58.3	55.3	52.7	50.3	48.1
34	[illegible]	[illegible]	[illegible]	[illegible]	79.3	72.9	68.0	63.9	60.4	57.3	54.5	[illegible]	49.7
I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75.9	70.6	66.2	62.5	59.2	56.3	53.7	51.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.4	73.3	68.6	64.6	61.2	58.1	55.4	53.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.2	71.0	66.8	63.2	60.0	57.2	54.6
R [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.6	73.6	69.1	65.3	61.9	59.0	56.3
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.4	71.5	67.4	63.9	60.8	58.0
E 40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.7	74.0	69.6	65.9	62.6	59.7
A 41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.7	71.9	67.9	64.5	61.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.9	74.3	70.1	66.5	63.3
T [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.9	72.3	68.4	65.1
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.0	74.6	70.5	67.0
I [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77.1	72.6	68.9
N [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.1	74.8	70.9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77.3	72.9
G 48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.3	75.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77.4
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

| | | |

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 35.0

WATER POTENTIAL, NEGATIVE BARS

							1.7		1.			1.4	
	9				3.8		3.4			3.0			2.6
				6.1	5.7	5.4	5.1	4.9			4.	4.1	3.9
					7.7		6.9	6.5	6.2		5.7	5.4	5.2
				10.2		9.1	8.6			7.4	7.1		6.5
	1	14.	1	12.3	11.5	10.9	10.3	9.8	9.4	8.9	8.5	8.2	7.9
		4		14.3	13.5	12.8	12.1	11.5	10.9		10.0		9.2
			17	16.4	15.5	14.6	13.8	13.1	12.5	12.0	11.4	11.0	10.5
9			19.	18.5	17.4	16.5	15.6	14.8	14.1	13.5	12.9	12.3	11.9
	25			20.7	19.4	18.3	17.4	16.5	15.7		14.3	13.7	13.2
11	.1	26.1			21.4		19.2		17.3	16.5	15.8	15.1	14.5
				24.9	23.4	22.1	21.0	19.9	18.9	18.1	17.3	16.6	15.9
	5	31		27.1	25.5	24.0	22.8	21.6	20.6		18.8	18.0	17.2
					27.5	26.0	24.6	23.3	22.2	21.2	20.2	19.4	18.6
15		36 1		31.5	29.6	27.9		25.0	23.8	22.7	21.7		20.0
	41		.0	33.7	31.6	29.8	28.2	26.8	25.5	24.3	23.2	22.2	21.3
17		4		35.9	33.7	31.8	30.1	28.5	27.1	25.9	24.7	23.7	22.7
1		4	4	38.2	35.8	33.8	31.9	30.3	28.8	27.5	26.2	25.1	24.1
1		46.6	4	40.4	38.0		33.8	32.1	30.5	29.1	27.8	26.6	25.5
1		4	4	42.7	40.1		35.7		32.2		29.3	28.0	26.9
		.0	48	45.1	4	39.8	37.6	35.6	33.9	32.3		29.5	28.3
	54		50	47.4	44.4	41.8	39.5	37.4	35.6	33.9	32.4	31.0	29.7
I			53.4	49.8	46.6	43.9	41.4	39.2		35.5	33.9	32.4	31.1
.4	66.1		56.1	52.2	48.9	46.0	43.4	4	39.0	37.2	35.5	33.9	32.5
	69			54.7	51.1	48.1		42.9	40.8	38.8		35.4	34.0
		66.7	61.5	57.2	53.4	50.2	47.3	4	42.5	40.5	38.6	36.9	35.4
	77.		4.4		55.8	52.4	49.3	46.7	44.3	42.2	40.2	38.5	36.8
O		7.4		62.3	58.1	54.5		48.6	46.1	43.9	41.8	40.0	38.3
		77..		65.0	60.6	56.8	53.4	50.5	47.9	45.6	43.4	41.5	39.8
V				67.8	63.0		55.5	52.5	49.7	47.3	45.1	43.1	41.2
31			77.1	70.6	65.6	61.3	57.7	54.4	51.6	49.0	46.7	44.6	42.7
				73.7	68.2	63.7	59.8	56.4	53.4	50.8	48.4	46.2	44.2
I				77.0	70.9	66.1	62.0	58.5	55.3	52.6	50.0	47.8	45.7
					73.8	68.6	64.3	60.5	57.3	54.3	51.7	49.4	47.2
T					77.0	71.2	66.6	62.6	59.2	56.2	53.4	51.0	48.8
						73.9	68.9	64.8	61.2	58.0	55.2	52.6	50.3
						76.9	71.4	67.0	63.2	59.9	56.9	54.3	51.9
							74.0	69.3	65.3	61.8	58.7	55.9	53.4
							76.9	71.6	67.4	63.7	60.5	57.6	55.0
							80.3	74.1	69.6		62.3	59.3	56.7
								76.8	71.8	67.7	64.2	61.1	58.3
								80.0	74.2	69.8	66.1	62.8	59.9
43											68.1		61.6
44									79.8	74.3	70.1	66.5	63.3
I										76.7	72.2	68.4	65.1
N										79.6	74.3		66.8
											76.7	72.3	68.6
48											79.4	74.4	70.5
												76.7	72.4
												79.2	74.5
1													76.6
													79.1
53													

1	2.4		2.1						
	4.9	4.							
7	17.2	16.0	14.9	14.0	13..				
8									
11									
14									
18	4								
19									
			78.2	71.5	66.3	62.0	58.3	55.0	52.1
R						77.4			
							74.4		
46									
47									
49									
51									
66									
67									

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 37.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	[illegible]	[illegible]	-10	[illegible]	+10	[illegible]	[illegible]	+40	[illegible]	+60
						WATER POTENTIAL, NEGATIVE BARS							
1	[illegible]	2.2	2.1	1.9	1.8	1.7	[illegible]	1.6	[illegible]	1.4	1.4	1.3	1.2
[illegible]	4.7	[illegible]	4.1	[illegible]	[illegible]	3.4	3.3	3.1	[illegible]	2.8	2.7	[illegible]	2.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.2	4.9	4.7	4.4	4.1	4.1	3.9	3.7
6	[illegible]	[illegible]	[illegible]	[illegible]	7.3	[illegible]	[illegible]	6.2	5.9	5.7	5.4	[illegible]	5.0
[illegible]	[illegible]	11.1	10.4	9.7	[illegible]	8.7	[illegible]	[illegible]	7.4	7.1	[illegible]	6.5	6.3
[illegible]	[illegible]	13.4	12.5	11.7	11.0	10.4	9.9	9.4	8.9	[illegible]	8.2	7.8	7.5
7	[illegible]	15.7	14.6	13.7	12.9	12.2	11.6	11.0	10.5	10.0	9.5	9.2	8.8
[illegible]	[illegible]	17.9	16.7	15.7	14.8	14.0	13.2	12.6	12.0	11.4	10.9	10.5	10.1
[illegible]	[illegible]	20.2	18.9	17.7	16.7	15.7	14.9	14.2	13.5	12.9	12.3	11.8	11.3
10	[illegible]	22.6	21.1	19.7	18.6	17.5	16.6	15.8	15.0	14.3	13.7	13.1	12.6
11	[illegible]	24.9	23.2	21.8	20.5	19.3	18.3	17.4	16.6	15.8	15.1	14.5	13.9
[illegible]	29.4	27.3	25.4	23.8	22.4	21.1	20.0	19.0	18.1	17.3	16.5	15.8	15.2
13	[illegible]	29.6	27.6	25.9	24.3	23.0	21.7	20.6	19.6	18.7	17.9	17.2	16.5
14	34.6	32.0	29.8	27.9	26.3	24.8	23.5	22.3	21.2	20.2	19.3	18.5	17.8
[illegible]	[illegible]	34.4	32.1	30.0	28.2	[illegible]	25.2	23.9	22.8	21.7	20.8	19.9	19.1
[illegible]	[illegible]	36.9	34.3	32.1	30.2	28.5	26.9	25.6	24.3	23.2	22.2	21.2	20.4
17	[illegible]	39.3	36.6	34.3	32.2	30.3	28.7	27.2	25.9	24.7	23.6	22.6	21.7
[illegible]	[illegible]	41.[illegible]	38.9	36.4	34.2	32.2	30.5	28.9	27.5	26.2	25.1	24.0	23.0
[illegible]	[illegible]	[illegible]	41.2	38.6	36.2	34.1	32.3	30.6	29.1	27.7	26.5	25.4	24.3
[illegible]	50.8	[illegible]	43.6	40.7	38.2	36.0	34.0	32.3	30.7	29.3	28.0	26.8	25.7
M [illegible]	53.6	49.5	46.0	42.9	40.3	37.9	35.8	34.0	32.3	30.8	29.4	28.2	27.0
22	56.6	52.1	48.4	[illegible]	42.3	39.9	37.7	35.7	33.9	32.3	30.9	29.6	28.3
I 23	[illegible]	54.8	50.8	47.4	44.4	41.8	[illegible]	37.4	35.6	33.9	32.4	31.0	29.7
24	[illegible]	57.5	53.3	49.7	46.5	43.8	41.3	39.2	37.2	35.5	33.8	32.4	31.0
C [illegible]	[illegible]	60.3	55.8	52.0	48.7	45.8	43.2	[illegible]	38.9	37.0	35.3	33.8	[illegible]
R 26	69.	63.2	58.4	54.3	50.8	47.8	45.1	42.7	40.5	38.6	36.8	35.2	33.8
27	[illegible]	66.1	61.0	56.7	[illegible]	49.8	[illegible]	[illegible]	42.2	40.2	[illegible]	[illegible]	35.1
O 28	[illegible]	69.2	63.7	59.1	55.2	[illegible]	48.9	46.3	43.9	41.8	39.9	38.1	36.5
[illegible]		72.4	66.4	61.6	57.5	53.9	50.8	48.1	45.6	43.4	41.4	39.6	37.9
V [illegible]		75.9	69.3	64.1	59.8	56.1	52.8	49.9	47.3	45.0	43.0	41.1	39.3
O [illegible]		80.0	72.3	[illegible]	62.1	58.2	54.8	51.8	49.1	46.7	44.5	42.5	40.7
32			75.6	69.4	64.5	60.4	56.8	[illegible]	50.8	48.3	46.1	44.0	42.1
I [illegible]			79.3	72.3	67.0	62.6	58.8	55.5	52.6	50.0	47.7	45.5	43.6
34				75.3	69.6	64.9	60.9	57.5	54.4	51.7	49.2	47.0	45.0
T [illegible]				78.7	72.2	67.2	63.1	59.4	[illegible]	53.4	50.9	[illegible]	46.4
[illegible]					75.1	69.7	65.2	61.4	58.1	55.1	52.5	50.1	47.9
37					[illegible]	72.2	67.5	63.4	60.0	56.9	54.1	51.6	49.4
R [illegible]						74.9	69.8	65.5	61.9	58.6	55.8	53.2	50.9
39						77.8	72.1	67.6	63.8	60.4	57.5	54.8	52.4
E [illegible]							74.7	69.8	65.8	62.3	59.2	56.4	53.9
A 41							77.4	72.1	67.8	64.1	60.9	58.0	55.4
[illegible]								74.5	69.9	66.0	62.6	59.6	56.9
D [illegible]								77.1	72.1	68.0	64.4	61.3	58.5
44								80.3	74.4	70.0	66.3	63.0	60.1
I 45									76.8	72.1	68.1	64.7	61.7
N 46									79.7	74.2	70.0	66.5	63.3
47										76.6	72.0	68.3	65.0
[illegible]										79.2	74.1	70.1	66.7
49											76.3	72.0	68.4
[illegible]											78.8	74.0	70.2
51												76.1	72.0
[illegible]												78.4	73.9
[illegible]													75.9
54													78.1
[illegible]													
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COOLING TIME IN SE

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 15.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 39.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	[illegible]	-4[illegible]	[illegible]	[illegible]	-1	0	+1[illegible]	+2[illegible]	+3[illegible]	+4[illegible]	+5[illegible]	+6[illegible]
1	2.3	2.1	2.0	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2
2	4.5	4.2	3.9	3.7	3.5	3.3	3.1	3.0	2.8	2.7	2.6	2.5	2.4
3	6.8	6.3	5.9	5.6	5.2	5.0	4.7	4.5	4.3	4.1	3.9	3.7	3.6
4	9.1	8.5	7.9	7.4	7.0	6.6	6.3	6.0	5.7	5.4	5.2	5.0	4.8
5	11.4	10.6	9.9	9.3	8.8	8.3	7.9	7.5	7.1	6.8	6.5	6.2	6.0
6	13.8	12.[illegible]	11.[illegible]	11.2	10.6	10.0	9.5	9.0	8.6	8.2	7.8	7.5	7.2
7	[illegible].1	15.[illegible]	14.[illegible]	13.1	12.3	11.7	11.1	10.5	10.0	9.6	9.1	8.8	8.4
8	[illegible].1	17.2	16.[illegible]	15.0	14.1	13.4	12.7	12.0	11.5	10.9	10.5	10.0	9.6
9	[illegible].8	19.4	[illegible]	16.9	15.9	15.1	14.3	13.6	12.9	12.3	11.8	11.3	10.9
10	[illegible]	[illegible].6	20.1	18.9	17.8	16.8	15.9	15.1	14.4	13.7	13.1	12.6	12.1
11	25.6	[illegible]	22.[illegible]	[illegible]	19.6	18.5	17.5	16.6	15.8	15.1	14.5	13.9	13.3
12	[illegible].1	26.[illegible]	24.[illegible]	22.8	21.4	20.2	19.1	18.2	17.3	16.5	15.8	15.1	14.5
13	[illegible]	[illegible].3	26.4	24.7	23.3	22.0	20.8	19.7	18.8	17.9	17.2	16.4	15.8
14	[illegible]	[illegible]	28.[illegible]	26.7	25.1	23.7	22.4	21.3	20.3	19.4	18.5	17.7	17.0
15	[illegible]	[illegible] 9	[illegible].6	28.7	27.0	[illegible]	24.1	22.9	21.8	20.8	19.9	19.0	18.3
16	[illegible]	[illegible].2	[illegible].8	30.7	[illegible]	27.2	25.8	24.5	23.3	22.2	21.2	20.3	19.5
17	[illegible].5	37.5	[illegible].0	32.7	30.7	29.0	27.4	26.0	24.8	23.6	22.6	21.6	20.8
18	43.1	[illegible]	[illegible].1	34.7	32.6	30.8	29.1	[illegible]	26.3	25.1	24.0	23.0	22.0
19	45.7	[illegible].3	[illegible].3	36.8	34.6	32.6	30.8	29.2	27.8	26.5	25.3	24.3	23.3
20	[illegible].4	44.7	[illegible]	38.9	36.5	34.4	32.5	30.9	29.3	28.0	26.7	25.6	24.6
M 21	[illegible].1	[illegible]	[illegible].8	40.9	38.4	36.2	34.2	32.5	30.9	29.4	28.1	26.9	25.8
22	[illegible]	49.6	[illegible].1	43.1	40.4	38.1	36.0	34.1	32.4	30.9	29.5	28.3	27.1
I 23	56.6	[illegible].1	[illegible].4	45.2	42.4	39.9	37.7	[illegible]	34.0	32.4	30.9	29.6	28.4
24	[illegible].4	54.7	50.7	47.3	44.4	41.8	39.5	37.4	35.5	33.9	32.3	31.0	29.7
C 25	[illegible].3	[illegible].3	[illegible].1	49.5	46.4	43.7	41.2	39.1	37.1	35.4	33.8	32.3	[illegible]
R 26	[illegible].3	[illegible].0	55.[illegible]	51.7	48.4	[illegible]	43.0	40.7	38.7	36.9	35.2	33.7	32.3
27	68.4	[illegible].7	[illegible]	54.0	50.5	47.5	44.8	42.4	40.3	38.4	36.6	35.0	33.6
O 28	71.7	[illegible].5	[illegible].5	56.2	[illegible]	49.4	46.6	44.1	41.9	39.9	38.1	36.4	34.9
29	[illegible].2	[illegible].4	[illegible]	58.5	54.7	51.4	48.5	45.9	[illegible]	41.4	39.5	37.8	36.2
V 30	79.2	71.4	[illegible]	60.9	56.9	53.4	[illegible]	47.6	45.2	43.0	41.0	39.2	37.6
O 31		[illegible]	[illegible]	63.3	59.0	55.4	52.2	[illegible]	46.8	44.5	42.5	40.6	38.9
32		[illegible].2	71.[illegible]	65.8	61.3	57.4	54.1	51.1	48.5	46.1	44.0	42.0	40.2
L 33			74.1	68.3	63.5	59.5	56.0	52.9	50.1	47.7	45.5	43.4	41.6
34			77.4	70.9	65.9	61.6	57.9	54.7	51.8	49.3	47.0	44.9	43.0
T 35				73.7	68.3	63.8	59.9	56.5	[illegible]	50.9	48.5	46.3	44.3
36				76.8	70.8	66.0	61.9	58.4	55.3	52.5	50.0	47.8	45.7
37					73.4	68.2	64.0	60.3	57.0	54.1	51.6	49.2	47.1
R 38					76.2	70.6	66.1	62.2	58.8	55.8	53.1	50.7	48.5
39					79.4	73.0	68.2	64.1	60.6	57.5	54.7	52.2	49.9
E 40						75.7	70.4	66.1	62.4	59.2	[illegible]	53.7	51.3
A 41						78.6	72.8	68.2	64.3	60.9	57.9	55.2	52.8
42							75.2	70.3	66.2	62.7	59.5	56.7	54.2
I 43							77.9	72.5	68.2	64.5	61.2	58.3	55.7
44								[illegible]	70.2	66.3	62.9	59.9	57.2
I 45								77.3	72.3	68.2	64.6	61.5	58.7
N 46								80.4	74.5	70.1	66.4	63.1	60.2
47									76.8	72.1	68.1	64.7	61.7
G 48									79.5	74.1	70.0	66.4	63.3
49										76.4	71.9	68.1	64.9
50										78.8	73.9	69.9	66.5
51											75.9	71.7	68.1
52											78.2	73.6	69.8
53												75.6	71.5
54												77.7	73.3
55												80.3	75.2
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 0.0

OFFSET FROM ZERO IN MICROVOLTS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WATER POTENTIAL, NEGATIVE BARS

	1	[illegible]	6.2	[illegible]	[illegible]	[illegible]	[illegible]	5.1	[illegible]	4.7	4.6	4.4	[illegible]	4.2
	2	[illegible]	12.6	[illegible]	11.6	11.1	10.7	10.3	9.9	[illegible]	9.3	9.0	8.7	8.5
	3	[illegible]	19.3	[illegible]	17.7	[illegible]	16.3	15.7	[illegible]	[illegible]	14.1	13.7	13.2	12.8
	4	[illegible]	26.2	[illegible]	24.0	[illegible]	22.1	21.2	20.5	[illegible]	19.1	18.4	17.9	17.3
	5	[illegible]	33.6	[illegible]	30.6	[illegible]	28.1	27.0	26.0	[illegible]	24.2	23.4	22.6	21.9
	6	[illegible]	41.4	[illegible]	37.5	35.9	34.4	33.0	31.8	[illegible]	29.5	28.5	27.5	[illegible]
	7	[illegible]	49.9	[illegible]	45.0	42.9	41.1	39.4	37.8	[illegible]	35.0	33.8	32.7	31.6
	8	[illegible]	59.5	[illegible]	53.2	50.6	48.2	46.1	44.2	[illegible]	40.9	39.4	38.0	36.7
	9		72.0	[illegible]	62.5	59.1	56.1	53.5	51.1	[illegible]	47.0	45.3	43.6	42.1
	10				76.3	69.7	65.4	61.8	58.8	[illegible]	53.7	51.6	49.6	47.8
	11							72.7	68.0	64.3	61.3	58.5	56.1	54.0
	12									76.4	70.6	66.7	63.5	60.8
	13												73.2	69.0
	14													
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COOLING TIME IN SECONDS -------------
PSYCHROMETER TEMPERATURE, CENTIGRADE

-10 0

1 4.1
2
3 19.4 18.5 17.6 16.9 16.1 15.5 [illegible] 12.1
4 20.1
6 41.7 39.4 37.5
7 50.2 47.4 44.9
8 60.0 56.2 53.0 47.7 [illegible] 4.4
9 58.6 55.4 47 44 40.7
10 68.7 [illegible] 44.5

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- [illegible]
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 2.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	5.7	[illegible]	5.2	[illegible]	4.8	[illegible]	4.4	4.2	4.1	[illegible]	3.8	3.7
[illegible]	[illegible]	11.5	11.0	10.5	10.1	9.6	[illegible]	8.9	8.6	[illegible]	8.0	7.7	7.5
[illegible]	[illegible]	[illegible]	16.8	16.0	15.3	14.7	14.1	13.5	13.0	[illegible]	12.1	11.7	11.3
[illegible]	[illegible]	[illegible]	22.7	21.7	20.7	19.8	19.0	18.3	17.6	[illegible]	16.4	15.8	15.3
5	[illegible]	30.4	28.9	27.5	26.3	25.2	24.1	23.2	22.3	[illegible]	20.7	20.0	19.3
6	39.5	37.4	35.4	[illegible]	[illegible]	30.7	29.4	[illegible]	[illegible]	26.1	25.1	24.3	23.5
[illegible]	[illegible]	44.7	[illegible]	[illegible]	[illegible]	36.5	34.9	[illegible]	[illegible]	30.9	29.7	28.7	27.7
[illegible]	56.3	52.8	49.7	47.1	44.7	42.6	40.7	[illegible]	[illegible]	35.9	34.5	33.3	32.1
[illegible]	66.7	61.9	58.0	[illegible]	[illegible]	49.1	46.8	44.7	[illegible]	41.1	39.5	38.0	36.6
[illegible]		74.0	67.8	[illegible]	[illegible]	56.2	53.4	[illegible]	[illegible]	[illegible]	44.7	43.0	41.4
11				74.7	[illegible]	64.3	60.7	[illegible]	54.9	52.4	50.2	48.2	[illegible]
[illegible]						75.4	69.5	[illegible]	61.8	[illegible]	[illegible]	53.8	51.7
[illegible]								[illegible]	70.3	66.2	62.8	59.9	57.4
14										76.5	70.9	67.0	63.7
[illegible]												77.1	71.5
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 4.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	5.4	5.2	4.9	4.7	4.5	4.3	4.1	4.0	3.8	3.7	3.5	3.4	3.3
	2	11.1	10.5	10.0	9.5	9.1	8.7	8.3	8.0	7.7	7.4	7.1	6.9	6.7
	3	16.8	15.9	15.1	14.4	13.8	13.2	12.6	12.1	11.6	11.2	10.8	10.4	10.1
	4	22.8	21.6	20.5	19.5	18.6	17.8	17.0	16.3	15.7	15.1	14.5	14.0	13.6
	5	29.0	27.4	26.0	24.7	23.5	22.5	21.5	20.6	19.8	19.1	18.4	17.7	17.1
	6	35.5	[illegible]	31.7	30.1	28.7	27.4	26.2	25.1	24.1	23.1	22.3	21.5	20.7
	7	42.4	[illegible]	37.7	35.8	34.0	32.4	31.0	29.6	28.4	27.3	26.3	25.3	24.4
	8	49.8	[illegible]	44.1	41.7	39.6	37.7	[illegible]	34.4	32.9	31.6	30.4	29.3	28.2
	9	[illegible]	[illegible]	[illegible]	48.0	45.5	43.2	41.1	39.3	37.6	36.1	34.7	33.4	32.2
	10	67.7	[illegible]	[illegible]	54.8	51.7	49.0	46.6	44.5	42.5	40.7	39.1	37.6	36.2
	11		[illegible]	[illegible]	62.4	[illegible]	55.3	52.5	49.9	47.6	45.6	43.7	42.0	40.4
	12				71.8	[illegible]	62.3	58.8	55.8	53.1	50.7	48.5	46.5	44.7
	13					77.7	70.7	66.1	62.3	59.0	56.2	53.6	51.3	49.3
	14							75.6	69.9	65.7	62.2	59.2	56.5	54.1
	15									74.1	69.2	65.4	62.1	59.3
	16											72.9	68.6	65.1
	17												77.7	72.0
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PREDICTED WATER POTENTIAL

[illegible] 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 6.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		[illegible]	4.5	4.3	[illegible]	[illegible]	[illegible]	3.6	3.4	[illegible]	3.2	3.1	[illegible]
	[illegible]	9.6	9.1	[illegible]	8.2	7.9	[illegible]	7.2	[illegible]	[illegible]	[illegible]	6.2	6.0
	15.4	14.5	13.8	13.1	12.5	11.9	[illegible]	10.9	10.5	10.1	9.7	9.4	9.1
4	20.8	19.6	18.6	17.6	16.8	16.0	[illegible]	14.7	14.1	13.6	13.1	12.6	12.2
	[illegible]	24.9	23.5	22.3	21.3	20.3	[illegible]	18.6	17.8	17.1	16.5	15.9	15.3
	[illegible]	30.3	28.7	27.2	25.8	[illegible]	[illegible]	22.5	[illegible]	20.7	20.0	19.2	18.5
	[illegible]	36.0	34.0	32.2	30.5	[illegible]	[illegible]	26.6	[illegible]	24.4	23.5	22.6	21.8
	[illegible]	41.9	39.5	37.4	35.4	[illegible]	[illegible]	30.7	[illegible]	28.2	27.1	26.1	25.2
	[illegible]	48.2	[illegible]	42.8	40.5	[illegible]	[illegible]	35.0	[illegible]	32.1	30.9	29.7	28.6
1	[illegible]	55.0	51.6	48.5	45.9	[illegible]	41.4	39.5	[illegible]	36.1	34.7	33.4	32.1
1	[illegible]	62.6	58.3	54.7	51.5	48.8	46.3	44.1	[illegible]	40.3	38.6	37.1	35.7
1		71.8	66.0	61.4	57.6	54.4	51.5	[illegible]	[illegible]	44.6	42.7	41.0	39.4
1			76.0	69.3	64.5	60.5	57.1	54.1	[illegible]	49.1	47.0	45.1	43.3
14					72.7	67.4	63.2	59.7	[illegible]	53.9	51.5	49.3	47.3
1						76.5	70.4	65.9	[illegible]	59.0	56.2	53.7	51.5
1								73.4	68.5	[illegible]	[illegible]	[illegible]	55.9
1									76.9	71.2	67.1	63.6	60.6
1											74.0	69.5	65.8
1												77.2	71.9
M	21												
	22												
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	29												
V	30												
O	31												
	32												
L	[illegible]												
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	42												
D	43												
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	47												
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	[illegible]												
	63												
	[illegible]												
	[illegible]												
	[illegible]												
	[illegible]												
	69												
	[illegible]												

11.4

30.7

55.8

4..1

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 8.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

			4.1			3.6		3.3	3.1		2.9		
				7.9	7.5	7.2	6.9	6.6					
			12.6	12.0	11.4	10.9	10.4	10.0	9.6		8.8	8.5	8.2
			17.0	16.1	15.3	14.6	14.0	13.4	12.8		11.9	11.4	
			21.5	20.4	19.4	18.5	17.6	16.9	16.2		14.9	14.4	13.9
6		27.7				22.4			19.6	18.8	18.1	17.4	16.8
		32.8				26.4			23.1	22.1	21.3	20.5	19.7
		38.0							26.6	25.5	24.5	23.6	22.7
9		43.6				34.8			30.2	29.0	27.8	26.8	25.8
						39.2					31.2	30.0	28.9
11	59.9		52.0	48.9	46.1		41.5	39.6		36.2	34.7	33.3	32.1
	67.9		58.2	54.5	51.3		46.0	43.8		39.9	38.3	36.7	35.3
	79.1		65.0	60.5	56.8		50.7	48.1		43.8	41.9	40.2	38.7
			73.2		62.7		55.6	52.7		47.9	45.8		42.1
1				75.9	69.6		61.0	57.6		52.1	49.7	47.6	45.7
16							66.9		59.5			51.5	
							74.0	68.1	64.8			55.6	
									70.7			60.0	
									78.9			64.7	
												70.0	
M												76.5	
I													
	24												
R	26												
	27												
V	30												
	32												
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	55												
	57												
	63												
	66												
	70												

PREDICTED WATER POTENTIAL

PSYCHROMETER TEMPERATURE, CENTIGRADE --- 10.0

OFFSET FROM ZERO IN MICROVOLTS

	-50	-40	-30	-20	-10					+40	+50	
	POTENTIAL, NEGATIVE BARS											
4	4.0					3.1	3.0	2.9				2.5
	8.1	7.7	7.3	7.0	6.6	6.3	6.1	5.8	5.6	4	5.2	
1		11.7	11.1	10.5	10.0	9.6	9.2					7.5
17 7		15.7	14.9	14.1		12.9	12.3	11.8	11.3	10.9	10.5	10.1
22	21.0	19.8		17.8	17.0	16.2	15.5	14.8	14.2	13.7	13.2	12.7
27 1	25.5	24.0	22.7	21.6	20.5	19.6	18.7	17.9	17.2	16.5	15.9	15.3
	30.1	28.4	26.8	25.4	24.2	23.1	22.0	21.1	20.2	19.4		18.0
37	34.9		31.0		27.9	26.6	25.4	24.3	23.3	22.4	21.5	20.7
6	39.8	37.4		33.4	31.7	30.2	28.8	27.6	26.4	25.4	24.4	23.5
48	45.0	42.2		37.6	35.7	33.9	32.4	30.9	29.6	28.4	27.3	26.3
54	50.4	47.2	44.4	41.9	39.7	37.7	36.0		32.9	31.5	30.3	29.1
		52.4	49.2	46.4	43.9	41.7	39.7	37.9	36.2		33.3	32.1
	62.5	58.0	54.3	51.1	48.3			41.5	39.6	38.0	36.4	35.0
1		64.2	59.8	56.0	52.8	50.0	47.5	45.2	43.2	41.3	39.6	38.1
	79.2	71.2	65.8	61.4	57.7		51.6	49.1			42.9	41.2
16			72.7	67.2	62.9	59.2			50.6	48.3	46.2	44.4
1				74.2	68.6	64.3		57.4	54.5	52.0	49.7	47.7
18					75.6	70.0	65.6	61.9	58.7	55.9	53.3	51.1
						77.0	71.2	66.8	63.1	59.9	57.1	54.6
20								72.4	68.0	64.3	61.1	58.3
21								80.2	73.6	69.1	65.4	62.3
22										74.7	70.2	66.5
23											75.9	71.2
												77.0
29												
32												
34												
40												
41												
4												
44												
4												
48												
49												
64												

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 12.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	-30	-20	-10		+20	+30	+40	+50
	WATER POTENTIAL, NEGATIVE BARS										
1	[illegible]	[illegible]	[illegible]	3.4	3.2	3.1	2.9	2.8	2.7	[illegible]	2.5	2.4	[illegible]
	[illegible]	7.6	7.2	[illegible]	6.	[illegible]	5.9	[illegible]	[illegible]	[illegible]	5.0	4.8	[illegible]
	12.2	11.5	10.9	10.3	[illegible]	9.3	[illegible]	8.5	8.1	7.8	7.5	7.2	7.0
4	16.	15.5	14.6	13.8	13.1	12.5	11.9	11.4	10.9	10.5	10.1	9.7	9.3
	[illegible]	19.5	18.4	[illegible]	16.5	15.7	15.0	14.3	13.7	13.2	12.7	12.2	11.7
6	25.2	[illegible]	22.3	21.1	20.0	19.0	18.1	17.3	16.6	15.9	15.3	14.7	14.2
7	[illegible]	27.9	26.3	24.9	23.6	22.4	21.3	20.4	19.5	18.7	17.9	17.3	16.6
8	[illegible]	[illegible]	30.4	28.7	27.2	25.8	24.6	23.4	22.4	21.5	20.6	19.8	19.1
[illegible]	[illegible]	36.8	34.6	32.6	30.8	29.3	27.9	26.6	25.4	24.3	23.4	22.5	21.6
10	44.4	41.4	[illegible]	36.6	34.6	32.8	31.2	29.8	28.5	27.2	26.1	25.1	24.2
11	49.6	46.3	43.3	[illegible]	38.5	[illegible]	34.7	33.0	31.6	30.2	29.0	27.8	26.8
12	[illegible]	51.3	48.0	45.1	42.5	40.2	38.2	36.4	34.7	33.2	31.8	30.6	29.4
[illegible]	[illegible]	56.7	52.8	49.5	[illegible]	44.1	41.8	39.8	38.0	36.3	34.8	33.4	32.1
[illegible]	67.9	62.4	58.0	54.2	51.0	48.1	45.6	43.3	41.3	39.4	37.8	36.2	34.8
[illegible]	75.9	68.8	63.5	59.2	55.5	52.3	49.5	46.9	44.7	42.7	40.8	39.1	37.6
[illegible]		76.6	69.7	64.5	60.3	56.6	53.5	50.7	48.2	46.0	43.9	42.1	40.4
[illegible]			77.3	70.5	65.4	61.3	57.7	54.6	51.9	49.4	47.2	45.2	43.3
[illegible]				77.9	71.2	66.3	62.2	58.7	55.7	52.9	50.5	48.3	46.3
19					78.6	71.9	67.1	63.1	59.6	56.6	53.9	51.5	49.3
[illegible]						79.1	72.6	67.8	[illegible]	60.5	57.5	54.9	52.5
[illegible]							79.7	73.2	68.5	64.6	61.3	58.4	55.8
[illegible]								80.3	73.7	69.1	65.4	62.1	59.2
[illegible]									80.9	74.3	69.7	66.0	62.8
[illegible]										81.7	74.8	70.3	66.6
25												75.2	70.8
[illegible]													75.7

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 14.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	[illegible]	[illegible]	[illegible]	3.2	3.0	2.[illegible]	[illegible]	2.6	2.5	2.4	2.3	[illegible]	2.1
2	7.[illegible]	[illegible].2	6.[illegible]	[illegible]	[illegible].1	[illegible]	5.5	5.3	5.0	4.8	4.6	4.5	4.3
3	11.5	10.[illegible]	[illegible].2	[illegible]	[illegible]	[illegible]	[illegible]	7.9	7.6	7.3	7.0	[illegible]	6.5
4	15.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].1	10.6	10.2	9.8	9.4	9.0	[illegible]
5	[illegible]	[illegible]	[illegible]7.3	16.3	15.5	14.[illegible]	[illegible]	13.4	12.8	12.3	11.8	11.3	10.9
6	[illegible].7	22.[illegible]	[illegible]	[illegible]	[illegible]	[illegible].8	16.9	16.2	15.5	14.8	14.2	13.7	13.2
7	[illegible].9	26.1	[illegible]	23.2	22.0	20.9	[illegible].9	19.0	18.1	17.4	16.7	16.0	15.4
8	[illegible]	[illegible].2	28.4	[illegible]	[illegible]	[illegible]	[illegible]	21.8	20.9	20.0	19.2	18.4	17.7
9	[illegible]	[illegible]	[illegible].2	30.4	28.7	27.2	25.9	24.7	23.6	22.6	21.7	20.8	20.1
10	[illegible].3	38.[illegible]	[illegible].2	34.1	32.2	30.5	[illegible].0	27.6	26.4	25.3	24.2	23.3	22.4
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].7	[illegible].3	[illegible].2	30.6	29.3	28.0	26.8	25.8	24.8
12	51.[illegible]	[illegible]	44.4	41.7	39.4	37.3	[illegible].4	33.7	32.1	30.7	29.5	28.3	27.2
13	56.2	52.[illegible]	[illegible].7	[illegible]	[illegible].1	[illegible].8	[illegible].7	36.8	35.1	33.5	32.1	30.8	29.6
14	[illegible].8	57.[illegible]	[illegible].2	49.9	46.9	44.3	42.0	40.0	38.1	36.4	34.8	33.4	32.1
15	[illegible]	[illegible]	[illegible].0	54.2	50.9	48.0	[illegible]	43.2	41.2	39.3	37.6	36.1	34.6
16	75.[illegible]	[illegible].3	63.[illegible]	58.7	55.1	51.9	49.1	46.6	44.3	42.3	40.4	38.7	37.2
17		75.[illegible]	[illegible].6	[illegible]	[illegible]	[illegible].9	[illegible].7	50.0	47.5	45.3	43.3	41.5	39.8
18			75.0	68.9	64.1	60.0	56.6	53.6	50.9	48.4	46.3	44.3	42.5
19				74.9	69.1	64.[illegible]	[illegible].6	57.3	54.3	51.7	49.3	47.1	45.2
20					74.9	69.[illegible]	64.9	61.1	57.9	55.0	52.4	50.1	48.0
21						74.[illegible]	[illegible].5	65.3	61.6	58.4	55.6	53.1	50.8
22							[illegible].8	69.7	65.6	62.1	59.0	56.2	53.7
23								74.8	69.9	65.9	62.5	59.5	56.8
24								81.7	74.8	70.1	66.2	62.9	59.9
25									81.2	74.7	70.2	66.5	63.2
26										80.8	74.7	70.3	66.7
27											80.4	74.7	70.5
28												80.1	74.7
29													79.8
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31													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 16.0

OFFSET FROM ZERO IN MICROVOLTS

POTENTIAL, NEGATIVE BARS

1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.7	[illegible]	2.5	2.4	[illegible]	2.2	[illegible]	[illegible]
[illegible]	[illegible]	6.8	[illegible]	6.0	[illegible]	5.4	[illegible]	5.0	4.7	4.5	4.4	[illegible]	4.0
[illegible]	[illegible]	[illegible]	[illegible]	9.1	[illegible]	[illegible]	7.8	7.5	7.1	6.9	6.6	6.3	6.1
[illegible]	13.[illegible]	[illegible]	12.2	11.6	11.0	10.5	[illegible]	[illegible]	9.2	8.8	8.5	8.2
[illegible]	17.3	[illegible]	[illegible]	14.6	[illegible]	13.2	12.6	12.0	11.5	11.1	10.6	10.2
[illegible]	[illegible]	[illegible]	18.6	17.6	16.7	15.9	15.2	14.5	13.9	13.3	12.8	12.3
7	26.3	[illegible]	[illegible]	21.8	20.7	19.6	18.7	17.8	17.0	16.3	15.6	15.0	14.5
[illegible]	[illegible]	[illegible]	[illegible]	25.1	23.8	22.5	21.4	20.4	19.5	18.7	17.9	17.2	16.6
[illegible]	34.[illegible]	[illegible]	[illegible]	28.5	26.9	25.5	24.3	23.1	22.1	21.2	[illegible]	19.5	18.7
1[illegible]	[illegible]	[illegible]	[illegible]	31.9	30.1	28.6	27.1	25.9	24.7	23.6	22.7	21.8	20.9
11	[illegible]	[illegible]	37[illegible]	35.4	[illegible]	31.6	30.1	28.6	27.3	26.1	25.0	24.0	23.1
1[illegible]	4[illegible].6	44.[illegible]	41.5	39.0	36.8	34.8	33.0	31.4	30.0	28.7	27.5	26.4	25.4
13	5[illegible]	[illegible]	4[illegible].4	42.6	40.2	38.0	36.0	34.3	32.7	31.3	29.9	28.7	27.6
14	[illegible].3	53.1	49.5	46.4	43.7	41.3	39.1	37.2	35.5	33.9	32.4	31.1	29.9
[illegible]	[illegible].5	57.[illegible]	[illegible].7	[illegible]	47.3	44.6	42.3	40.2	38.3	36.5	35.0	33.5	32.2
16	[illegible].2	[illegible].6	[illegible]	[illegible]	51.0	48.0	45.5	43.2	41.1	39.2	37.5	36.0	34.5
17	74.6	68.0	62.[illegible]	58.5	54.8	51.6	48.8	46.3	44.0	42.0	40.1	[illegible]	36.9
[illegible]		73.9	67.8	62.9	58.8	55.3	52.2	49.4	47.0	44.8	42.8	41.0	39.3
1[illegible]		[illegible].9	73.4	67.6	63.0	59.1	55.7	52.7	50.1	47.7	45.5	43.6	41.8
20			[illegible]	[illegible]	67.5	63.1	[illegible]	56.1	53.2	50.6	48.3	46.2	44.3
M 22				79.2	72.4	67.4	63.2	59.6	56.4	53.6	51.1	48.9	46.8
[illegible]					78.2	72.0	67.2	63.3	59.8	56.8	54.1	51.6	49.4
I 23						77.4	71.7	67.1	63.3	60.0	57.1	54.5	[illegible]
24							76.7	71.[illegible]	[illegible]	63.4	60.2	57.4	54.8
25								76.1	71.1	67.0	63.5	60.4	57.6
F 26								82.6	75.5	70.8	66.9	63.5	60.5
27									81.2	75.0	70.5	66.8	63.6
[illegible]										80.2	74.6	70.3	66.7
29											79.4	74.2	70.1
V 30												78.6	73.8
[illegible]													78.0
L [illegible]													
34													
Z [illegible]													
[illegible]													
37													
F 38													
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E 4[illegible]													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, [illegible] 18.0

WATER POTENTIAL, NEGATIVE BARS

	1	[illegible]	[illegible]	[illegible]	2.9	[illegible]	[illegible]	[illegible]	2.3	2.2	[illegible]	2.1	2.0	1.9
	[illegible]	[illegible]	[illegible]	[illegible]	5.7	[illegible]	[illegible]	4.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.8
	[illegible]	10.4	[illegible]	[illegible]	[illegible]	8.2	[illegible]	[illegible]	[illegible]	[illegible]	6.5	[illegible]	6.	[illegible]
	4	[illegible]	[illegible]	12.3	11.6	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.3	8.0	[illegible]
	[illegible]	[illegible]	[illegible]	15.5	14.6	13.8	[illegible]	12.5	11.9	[illegible]	[illegible]	10.4	10.0	9.6
	[illegible]	[illegible]	19.9	[illegible]	17.	[illegible]	[illegible]	15.	14.3	13.7	13.1	12.6	12.1	11.6
	[illegible]	[illegible]	.4	21.	20.	[illegible]	[illegible]	[illegible]	16.8	16.0	15.3	14.7	14.1	13.6
	[illegible]	[illegible]	26	[illegible]	23.	[illegible]	[illegible]	[illegible]	19.3	18.4	17.6	16.9	16.2	15.6
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.4	24.1	[illegible]	21.8	20.8	19.9	19.1	18.3	17.6
	[illegible]	[illegible]	34.	[illegible]	[illegible]	28.4	26.9	[illegible]	24.3	23.2	22.2	21.3	20.4	19.6
	[illegible]	[illegible]	37.	[illegible]	.3	31.5	29.	[illegible]	26.9	25.7	24.6	23.5	22.6	21.7
	[illegible]	44.9	41.	[illegible]	36.7	34.6	32.	31.0	29.5	28.2	26.9	25.8	24.7	23.8
	[illegible]	[illegible]	[illegible]	41.7	[illegible]	[illegible]	.7	33.	32.2	30.7	29.3	28.1	26.9	25.9
	[illegible]	[illegible]	49.7	46.4	43.	[illegible]	.7	36.	34.9	33.2	31.7	30.4	29.1	28.0
	[illegible]	[illegible]	.9	50.2	47.0	44.2	41.	39.6	37.6	35.8	34.2	32.7	31.4	30.1
	[illegible]	[illegible]	53.3	54.	.6	47.6	44.9	[illegible]	40.4	38.4	36.7	35.1	33.6	32.3
	[illegible]	.4	62	[illegible]	51.4	51.0	48.1	[illegible]	43.2	41.1	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	74.3	67.	[illegible]	.3	54.6	51.4	48.6	46.1	43.8	41.8	39.9	38.2	36.7
	19	81.8	73.2	67.2	.4	58.3	54.8	[illegible]	49.0	46.6	44.4	42.4	40.6	38.9
	[illegible]		79.	[illegible]	[illegible]	[illegible]	.3	55.	52.0	49.4	47.0	44.9	43.0	41.2
M	.1			77.9	[illegible]	[illegible]	[illegible]	[illegible]	55.1	52.3	49.8	47.5	45.4	43.5
	[illegible]				[illegible]	[illegible]	.8	[illegible]	58.3	55.3	52.5	50.1	47.9	45.9
I	[illegible]					75.4	69.	[illegible]	61.6	58.3	55.4	52.8	50.4	48.3
	[illegible]					81.4	74.4	69.3	65.1	61.5	58.3	55.5	53.0	50.7
C	25						.7	73.	68.8	64.8	61.4	58.3	55.6	53.2
	26							[illegible]	72.7	68.3	64.5	61.3	58.3	55.7
	[illegible]								77.1	72.0	67.8	64.3	61.1	58.3
	[illegible]								83.1	76.1	71.4	67.4	64.0	61.0
	29									81.1	75.2	70.8	67.1	63.8
	[illegible]										79.7	74.4	70.3	66.7
	[illegible]											78.5	73.7	69.8
	[illegible]												77.5	73.1
L	[illegible]												82.5	76.6
	[illegible]													[illegible]
T	[illegible]													
	[illegible]													
R	[illegible]													
	39													
E	[illegible]													
A	41													
	[illegible]													
I	43													
	[illegible]													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 20.0

OFFSET FROM ZERO IN MICROVOLTS

			-40	-30	-20	-10		+10	+20	+30	+40	+50	+60

WATER POTENTIAL, NEGATIVE BARS

		3.1		2.7	2.6		2.3	2.2	2.1		1.9	1.9	1.8
				5.5	5.2			4.5	4.3	4.1	3.9		
	1.0	9.3		8.2	7.8			6.7	6.4	6.1		5.7	
4	13.4	12.5	11.7	11.0	10.4			9.0	8.6	8.2	7.9	7.6	7.3
		15.7	14.7	13.9	13.1	12.4	11.8	11.3	10.8	10.3			
6		19.0	17.8	16.7	15.8	15.0	14.2	13.6	13.0	12.4	11.9	11.4	11.0
7		22.2	20.9	19.6	18.5	17.6	16.7	15.9	15.2	14.5	13.9	13.4	12.8
		25.6	24.0	22.6	21.3	20.2	19.2	18.2	17.4	16.7	16.0	15.3	14.7
9		29.0	27.1	25.5	24.1		21.7	20.6	19.7	18.8	18.0	17.3	16.6
		32.4		28.5	26.9		24.2	23.0	21.9		20.1	19.3	18.5
11		35.9		31.6	29.8	28.2	26.7	25.4	24.2		22.2	21.3	
	42.5	39.5	36.9	34.7	32.7	30.9		27.9	26.6	25.4	24.3	23.3	22.4
			40.3	37.8	35.6	33.7	31.9	30.3	28.9	27.6	26.4	25.4	24.4
14		46.9	43.8	41.0	38.6	36.5		32.8	31.3	29.9	28.6	27.4	26.3
		50.8	47.3	44.3	41.6	39.3	37.2	35.4	33.7	32.2	30.8	29.5	28.3
		54.7	50.9	47.6	44.7	42.2	40.0	37.9	36.1	34.5	33.0	31.6	30.3
		58.8	54.6	51.0	47.9	45.2	42.7	40.6	38.6	36.8	35.2	33.7	32.4
		63.1	58.5	54.6	51.2	48.2	45.6	43.2	41.1	39.2	37.5	35.9	34.4
19	74.	67.7	62.5	58.2	54.5	51.3	48.4	45.9	43.6	41.6	39.7	38.0	36.5
20	80.6	72.6		62.0	57.9	54.4	51.4			44.0	42.0	40.2	38.6
M 21		78.2	71.3	65.9	61.5	57.7	54.4	51.5	48.9		44.4	42.5	40.7
			76.3	70.1	65.2	61.0	57.5	54.3	51.5	49.0	46.8	44.7	42.9
I			82.6	74.7	69.1	64.5	60.7	57.3	54.3	51.6	49.2	47.0	45.0
24				80.0	73.3	68.2		60.3	57.1	54.2	51.7	49.4	47.3
25					78.1	72.1	67.4	63.4	60.0	56.9	54.2	51.7	49.5
R						76.4	71.1	66.7	63.0	59.7	56.8		51.8
27						81.7	75.1	70.2	66.1	62.5	59.4	56.6	54.1
28							79.6	73.9	69.3	65.5	62.1		56.5
29								78.0	72.8	68.6	65.0	61.8	59.0
V										71.8		64.5	61.5
O 31									81.0	75.3	71.0	67.3	64.0
32										79.3	74.3	70.2	66.7
I											77.9	73.3	69.5
34											82.3	76.7	72.4
												80.5	75.6
36													79.1
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 22.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	-	[illegible]	-30	-20	-10	0	+10	+20	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.2	2.1	[illegible]	[illegible]	1.9	1.8	1.7
[illegible]	6.3	[illegible]	[illegible]	5.2	[illegible]	[illegible]	4.5	4.2	[illegible]	3.9	[illegible]	3.6	3.4
[illegible]	9.6	[illegible]	[illegible]	7.9	[illegible]	7.1	6.7	[illegible]	6.1	5.8	5.6	5.4	5.2
[illegible]	12.8	12.0	11.2	10.6	[illegible]	9.4	[illegible]	8.5	8.2	7.8	[illegible]	7.2	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	13.2	[illegible]	11.8	[illegible]	10.7	[illegible]	[illegible]	9.4	9.0	8.6
[illegible]	19.4	[illegible]	17.0	16.0	[illegible]	14.3	13.6	12.9	12.3	11.8	11.3	10.8	10.4
[illegible]	22.8	[illegible]	[illegible]	18.7	[illegible]	16.7	15.9	15.1	14.4	13.8	13.2	12.7	12.2
[illegible]	26.2	24.4	22.9	21.5	[illegible]	19.2	18.2	17.3	16.5	15.8	15.1	14.5	14.0
9	[illegible]	27.6	25.9	24.3	[illegible]	21.7	20.6	19.6	18.7	17.8	17.1	16.4	15.7
[illegible]	[illegible]	[illegible]	28.9	27.1	25.6	[illegible]	22.9	21.8	20.8	19.9	19.0	18.3	17.5
11	[illegible]	[illegible]	32.0	30.0	[illegible]	26.7	25.3	24.1	[illegible]	22.0	21.0	20.2	19.4
[illegible]	40.4	[illegible]	35.1	32.9	[illegible]	29.3	27.8	26.4	25.2	24.0	23.0	22.1	21.2
[illegible]	[illegible]	[illegible]	38.3	35.9	[illegible]	31.9	30.2	28.7	27.4	26.1	25.0	24.0	23.0
[illegible]	[illegible]	44.5	41.5	38.9	[illegible]	34.5	32.7	31.1	29.6	28.3	27.0	25.9	24.9
[illegible]	[illegible]	48.1	44.8	[illegible]	[illegible]	37.2	35.2	33.4	31.8	30.4	29.1	27.9	26.7
16	[illegible]	[illegible]	48.1	45.0	[illegible]	39.9	37.8	35.8	34.1	32.6	31.1	29.8	28.6
17	[illegible]	[illegible]	51.5	48.2	[illegible]	42.6	40.3	38.3	36.4	34.7	33.2	31.8	30.5
[illegible]	[illegible]	[illegible]	55.1	[illegible]	[illegible]	[illegible]	42.9	40.7	38.7	36.9	35.3	33.8	32.4
[illegible]	[illegible]	[illegible]	58.7	54.7	[illegible]	48.3	45.6	43.2	41.1	39.2	37.4	35.8	34.4
[illegible]	[illegible]	67.6	62.4	58.1	[illegible]	[illegible]	48.3	45.8	43.5	41.4	39.6	37.9	36.3
M [illegible]	[illegible]	72.2	66.4	[illegible]	[illegible]	54.1	51.1	48.3	45.9	43.7	41.7	39.9	38.3
[illegible]		[illegible]	70.5	65.3	[illegible]	57.1	53.9	51.0	48.4	46.0	43.9	42.0	40.3
I 23		[illegible]	75.0	69.1	64.3	60.3	56.7	53.6	50.9	48.4	46.2	44.1	42.3
[illegible]			80.2	73.2	[illegible]	63.5	59.7	56.4	53.4	50.8	48.4	46.3	44.3
[illegible]				77.8	[illegible]	66.8	62.7	59.2	56.0	[illegible]	50.7	48.5	46.4
R [illegible]				83.5	[illegible]	70.3	65.9	62.0	58.7	55.7	53.1	50.7	48.5
[illegible]					[illegible]	74.1	69.2	65.0	61.4	58.3	55.4	52.9	50.6
[illegible]						78.2	72.6	68.1	64.2	60.9	57.9	55.2	52.8
[illegible]						83.5	76.4	71.3	67.2	63.5	60.4	57.5	54.9
V [illegible]							80.7	74.8	70.2	66.3	62.9	59.9	57.2
[illegible]								78.6	73.4	69.2	[illegible]	62.3	59.5
[illegible]								83.4	76.9	72.2	68.2	64.8	61.8
L 33									80.9	75.4	71.1	67.4	64.2
[illegible]										78.9	74.1	70.1	66.6
[illegible]										83.4	77.3	72.9	69.2
[illegible]											81.0	75.9	71.8
37												79.2	74.7
R 38												83.3	77.7
[illegible]													[illegible]
42													
D 43													
44													
47													
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64													
65													

PSYCHROMETER TEMPERATURE,

WATER POTENTIAL (NEGATIVE BARS)

[illegible]

POTEN[illegible]RS

	[illegible]	[illegible]	-40	-30	-20	-10	0	[illegible]	+20	+30	[illegible]	[illegible]	[illegible]
[illegible]			2.7	2.5	[illegible]	2.2	[illegible]	2.0	1.9	1.8	[illegible]	[illegible]	1.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.9	3.7	[illegible]	3.4	[illegible]
[illegible]	[illegible]	[illegible]	5.0	[illegible]	[illegible]	6.7	[illegible]	6.1	[illegible]	[illegible]	[illegible]	5.1	[illegible]
[illegible]	[illegible]	11.5	10.7	10.1	[illegible]	[illegible]	8.6	8.1	[illegible]	7.4	[illegible]	6.8	[illegible]
5	[illegible]	14.4	13.5	12.7	11.9	11.3	10.7	10.2	9.7	9.3	[illegible]	[illegible]	8.2
[illegible]	[illegible]	17.4	16.2	15.3	14.4	[illegible]	12.9	12.3	11.7	11.2	10.7	10.3	9.9
[illegible]	[illegible]	20.3	[illegible]	17.9	16.9	15.9	15.1	14.4	13.7	13.1	12.6	12.0	11.6
[illegible]	[illegible]	[illegible]	21.8	[illegible]	19.3	18.3	17.3	16.5	15.7	15.0	14.4	13.8	[illegible]
[illegible]	[illegible]	[illegible]	24.7	23.2	[illegible]	20.6	19.6	18.6	17.7	17.0	16.2	15.6	15.0
[illegible]	[illegible]	[illegible]	27.6	25.9	24.4	23.0	21.8	20.8	19.8	18.9	18.1	17.3	16.7
[illegible]	[illegible]	[illegible]	30.5	28.6	26.9	25.4	24.1	22.9	21.8	20.8	20.0	19.1	18.4
[illegible]	[illegible]	35.8	33.4	31.3	29.5	27.9	26.4	25.1	23.9	22.8	21.8	20.9	20.1
[illegible]	[illegible]	[illegible]	[illegible]	34.1	[illegible]	30.3	[illegible]	27.3	26.0	24.8	23.7	22.7	21.8
[illegible]	45.7	[illegible]	39.4	[illegible]	34.7	32.8	31.1	[illegible]	28.1	26.8	25.6	24.6	23.6
[illegible]	49	45.7	42.5	[illegible]	37.4	35.3	[illegible]	31.7	30.2	[illegible]	27.6	[illegible]	25.3
16	[illegible]	49.1	45.6	42.7	40.1	37.8	35.8	34.0	[illegible]	[illegible]	[illegible]	28.2	27.1
17	56.9	52.5	[illegible]	45.6	42.9	[illegible]	[illegible]	[illegible]	[illegible]	32.9	31.4	30.1	28.9
[illegible]	[illegible]	56.1	52.1	[illegible]	[illegible]	43.0	40.6	[illegible]	36.7	35.0	33.4	32.0	30.7
[illegible]	[illegible]	59.8	55.4	51.7	[illegible]	[illegible]	43.1	40.9	38.9	37.0	35.4	33.9	32.5
[illegible]	[illegible]	63.6	[illegible]	54.8	[illegible]	48.3	45.6	43.2	41.1	39.2	37.4	35.8	34.3
21	74.0	67.6	62.4	58.0	54.3	51.0	48.2	45.6	43.3	41.3	39.4	37.7	36.2
[illegible]	[illegible]	71.8	66.0	61.3	57.3	53.8	50.8	48.0	45.6	43.4	41.5	39.7	38.0
[illegible]		76.3	69.9	64.7	60.4	[illegible]	53.4	50.5	47.9	45.6	[illegible]	41.6	39.9
[illegible]		81.6	74.0	[illegible]	63.6	59.6	56.1	53.0	50.3	47.8	45.6	43.6	41.8
[illegible]			[illegible]	72.0	66.	62.5		[illegible]	52.7	50.1	47.7	45.6	43.7
[illegible]			84.3	76.0	70.3	65.6	61.6	58.2	55.1	52.3	49.9	47.6	[illegible]
27				80.5	73.9	68.8	[illegible]	[illegible]	57.6	54.7	52.1	49.7	[illegible]
28					77.9	72.2	67.5	[illegible]	60.1	57.0	54.3	51.8	49.5
[illegible]					[illegible]	75.8	70.6	66.4	[illegible]	59.4	[illegible]	53.9	51.5
[illegible]						79.7	73.9	69.3	[illegible]	61.9	58.8	56.1	[illegible]
31							77.5	72.3	68.1	64.4	61.1	[illegible]	55.6
[illegible]							[illegible]	75.6	70.9	[illegible]	63.5	[illegible]	57.7
33								79.1	73.9	69.7	66.0	62.8	59.9
[illegible]								83.4	77.1	72.5	[illegible]	65.1	62.0
35									[illegible]	75.4	71.1	67.5	64.3
[illegible]										78.6	73.9	70.0	66.6
[illegible]											[illegible]	72.6	68.9
38											80.1	[illegible]	71.3
[illegible]											84.1	78.2	73.9
[illegible]												[illegible]	76.6
44													

PREDICTED WATER POTENTIAL

[illegible] ---------------- [illegible]
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 26.0

OFFSET FROM ZERO IN MICROVOLTS

		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+10	+20	+30	+40	+50	+60
		WATER POTENTIAL, NEGATIVE BARS												
	1	2.9	2.7	2.5	2.4	2.3	2.1	2.0	1.9	1.8	1.8	1.7	1.6	1.6
	2	5.9	5.5	5.1	4.8	4.5	4.3	4.1	3.9	3.7	3.5	3.4	3.2	3.1
	[illegible]	8.8	8.2	7.7	7.2	6.8	6.4	6.1	5.8	5.5	5.3	5.1	4.9	4.7
	4	11.8	11.0	10.3	9.7	9.1	8.6	8.2	7.8	7.4	7.1	6.8	6.5	6.3
	5	14.8	13.8	12.9	12.1	11.4	10.8	10.2	9.7	9.3	8.9	8.5	8.2	7.8
	[illegible]	[illegible]	16.6	[illegible]	14.6	13.8	13.0	12.3	11.7	11.2	10.7	10.2	9.8	9.4
	[illegible]	[illegible]	19.5	[illegible]	17.1	16.1	15.2	14.4	13.7	13.1	12.5	12.0	11.5	11.0
	[illegible]	[illegible]	[illegible]	[illegible]	19.6	[illegible]	17.5	16.5	15.7	[illegible]	14.3	13.7	13.1	12.6
	[illegible]	[illegible]	[illegible]	[illegible]	22.1	[illegible]	19.7	18.7	17.7	16.9	16.1	15.5	14.8	14.2
	[illegible]	[illegible]	[illegible]	[illegible]	24.7	[illegible]	22.0	[illegible]	19.8	18.8	18.0	17.2	16.5	15.8
	[illegible]	33.6	[illegible]	[illegible]	27.3	25.7	24.2	23.0	21.8	20.8	19.8	19.0	18.2	17.5
	12	[illegible]	[illegible]	[illegible]	29.9	[illegible]	26.5	25.1	23.9	22.7	21.7	[illegible]	19.9	19.1
	[illegible]	[illegible]	[illegible]	34.7	32.5	[illegible]	28.9	27.3	26.0	[illegible]	23.6	22.6	21.6	20.7
	[illegible]	[illegible]	[illegible]	[illegible]	35.2	33.1	31.2	29.5	28.0	26.7	25.5	24.4	23.3	22.4
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35.6	33.6	31.8	30.2	[illegible]	27.4	26.2	25.1	24.1
	[illegible]	[illegible]	[illegible]	[illegible]	40.6	[illegible]	36.0	34.0	32.3	[illegible]	29.3	28.0	26.8	25.7
	17	[illegible]	[illegible]	[illegible]	43.4	40.7	38.4	36.3	34.4	32.7	31.2	29.8	28.6	27.4
	[illegible]	[illegible]	[illegible]	[illegible]	46.2	43.3	40.8	38.6	36.6	34.8	33.2	31.7	30.3	29.1
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43.3	40.9	38.8	36.9	35.1	33.6	32.1	30.8
	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45.8	43.2	41.0	38.9	37.1	35.4	33.9	32.5
M	21	[illegible]	63.7	[illegible]	54.9	[illegible]	48.3	45.6	43.2	41.0	39.1	37.3	35.7	34.2
	[illegible]	73.8	67.4	[illegible]	57.9	54.1	[illegible]	48.0	45.5	43.2	41.1	39.2	37.5	[illegible]
I	23	[illegible]	[illegible]	[illegible]	61.0	57.0	53.5	50.5	47.7	45.3	43.2	41.2	39.4	37.7
	[illegible]		[illegible]	69.2	64.2	[illegible]	56.2	52.9	[illegible]	47.5	45.2	43.1	41.2	39.5
C	[illegible]		[illegible]	[illegible]	67.4	[illegible]	58.9	55.4	52.4	49.7	47.3	45.1	43.1	41.3
	[illegible]			77.0	70.9	[illegible]	61.7	58.0	54.8	[illegible]	49.4	47.1	45.0	43.1
	[illegible]			[illegible]	74.5	[illegible]	[illegible]	60.6	57.2	54.2	51.5	49.1	46.9	44.9
	[illegible]				78.4	[illegible]	67.5	63.3	59.7	56.5	53.7	51.1	48.8	46.7
	[illegible]				83.1	[illegible]	70.5	66.1	62.2	58.9	55.9	53.2	50.8	48.6
V	[illegible]					[illegible]	73.7	68.9	64.8	[illegible]	58.1	55.3	52.8	50.5
	[illegible]						77.2	71.9	67.5	63.7	[illegible]	57.4	54.8	52.4
	[illegible]						81.0	75.0	70.3	66.2	62.7	59.6	[illegible]	54.3
	[illegible]							78.4	73.1	68.8	65.1	61.8	58.9	56.2
	[illegible]							82.2	[illegible]	71.5	67.5	64.0	61.0	58.2
	35								79.5	74.3	70.0	66.4	63.1	60.2
	[illegible]								83.4	77.3	72.6	68.7	65.3	62.2
	[illegible]									80.5	75.4	71.2	67.5	64.3
F	38										78.3	73.7	69.8	66.5
	[illegible]										81.6	76.4	72.2	68.6
E	[illegible]											79.3	74.7	70.9
A	[illegible]											82.6	77.4	73.2
	[illegible]												80.2	75.7
D	[illegible]												83.6	78.3
	[illegible]													81.1
I	[illegible]													
	46													
	49													
	63													
	67													

MICROVOLT READING

1						[illegible]			
2	5.7								
3				7.1					
4	11.6			9.5		[illegible].4			
5	14.5		1[illegible].6		11.[illegible]				
6	17.5			14.3					
7		19.1	17.8	1[illegible].7		14.9	14.1		
8		21.9		19.2		17.1			14.[illegible]
9								17.3	
10		27.6	25.7	24.1	22.7			19.3	
11									
12									
13	39.2			31.7					
14			36.7					27.4	
15					34.7				
16		45.5							
17			45.2	42.3		37.4			
18	56.2	51.9	48.2	45.0					
19			51.2			42.[illegible]			
20	63.6		54.2	50.6		44.6			
21							44.4	4[illegible].1	
22	71.5		60.5						
23	75.9								
24	80.3		67.2						
25		77.2							
26		82.0	74.4						
27			78.4	72.1					
28					70.0		61.4		
29									
30				84.4	76.8				
31						74.4			
32						77.8	72.4		
33								70.7	
34									
35									
40									
41									
43									
44									
47									
51									
56									
61									
62									
65									

PREDICTED WATER POTENTIAL

30.0

OFFSET FROM ZERO IN MICROVOLTS

	-50	-20	-10		+40	+50	+60
				POTENTIAL, NEGATIVE BARS			
1	2.6	2.2	1.9	1.8	1.8	1.7	1.6	1.5	1.9
		4.3		3.7	3.5	3.4	3.2	3.1	3.0
						5.1			4.5
	10.5	8.7	8.2	7.4		6.8		6.2	
	13.2	12.4	11.6	10.3	9.8			7.8	7.5
	15.9	14.0	13.2	12.4	11.2	10.7	10.2	9.4	9.0
	18.6	17.4	16.	15.4	14.5	13.1	12.5	11.9	11.4	10.9	10.5
	21.4	20.0	18.7	17.6	16.7	15.8	15.0	14.3	13.7	13.1	12.5	12.0
	24.2	22.6	21.2				16.9	16.1	15.4	14.7	14.1	13.6
		25.2	23.6	22.2	21.0	19.9	18.9	18.0	17.1	16.4	15.7	15.1
11	29.8			24.5	23.1	21.9	20.8	19.8	18.9	18.1	17.3	16.6
	32.6	30.4	28.5	26.8	25.3	24.0	22.8	21.7	20.7	19.8	18.9	18.2
	35.5	33.1	31.0	29.2	27.5	26.0	24.7	23.5	22.5	21.5	20.6	19.7
	38.5	35.8	33.5	31.5	29.7	28.1	26.7	25.4	24.3	23.2	22.2	21.3
15	41.4	38.6	36.1	33.9	32.0	30.2	28.7	27.3	26.1	24.9	23.9	22.9
	44.4		38.6	36.3	34.2	32.4	30.7	29.2	27.9		25.5	24.5
		44.1	41.2		36.5	34.5	32.7	31.1	29.7	28.4	27.2	26.1
	50.6	47.0	43.9	41.2	38.8	36.7	34.8	33.1	31.5	30.1		27.7
	53.7		46.6	43.7	41.1	38.9	36.8	35.0	33.4	31.9	30.5	
	56.9	52.8	49.3	46.2	43.5	41.1	38.9	37.0	35.2	33.7	32.2	30.9
21	60.2	55.8	52.0	48.7	45.8	43.3	41.0	39.0	37.1	35.4	33.9	32.5
	63.6	58.9		51.3	48.2	45.5	43.1	41.0		37.2	35.6	34.2
	67.2	62.0	57.7	53.9	50.7	47.8	45.3	43.0	40.9	39.1	37.4	
	70.8	65.2	60.6	56.6	53.2	50.1	47.4	45.0	42.9	40.9	39.1	37.5
	74.7	68.6	63.6	59.3	55.7	52.5	49.6	47.1	44.8	42.7	40.9	39.1
		72.0	66.6	62.1		54.8	51.8	49.2	46.8	44.6	42.6	40.8
27	83.9		69.8	65.0	60.8	57.2	54.1	51.3		46.5	44.4	42.5
28		79.8	73.2	67.9	63.5		56.4	53.4	50.8	48.4		44.2
		84.9	76.7	71.0	66.2	62.2	58.7	55.6	52.8	50.3	48.0	46.0
			80.6	74.2	69.1	64.8	61.0	57.8	54.9	52.2	49.9	47.7
31				77.6	72.0	67.4	63.5	60.0	56.9	54.2	51.7	49.5
				81.3	75.1	70.1	65.9	62.3	59.1	56.2	53.6	51.2
					78.4	72.9	68.5	64.6		58.2	55.5	53.0
					82.0	75.9	71.1	67.0	63.4	60.3	57.4	54.9
						79.1	73.8	69.4	65.7	62.3	59.4	56.7
						82.7	76.7	72.0	68.0	64.5	61.4	58.6
							79.7	74.6	70.3	66.6	63.4	
							83.3	77.4	72.8		65.4	62.4
								80.4		71.2	67.5	64.3
								83.9		73.5	69.7	66.3
41									81.0	76.0	71.9	68.4
									84.6	78.6	74.2	70.5
43										81.5	76.6	72.6
44											79.2	74.9
											82.0	77.2
46												79.7
												82.5
51												
1												
61												

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 30.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.9	1.8	1.7	1.6	1.5	1.4
	2	5.4	[illegible]	4.7	4.4	4.1	[illegible]	3.7	[illegible]	3.4	3.2	3.1	3.0	2.8
	3	[illegible]	[illegible]	7.1	[illegible]	[illegible]	[illegible]	5.6	5.3	5.1	4.8	4.6	4.4	4.3
	4	10.9	[illegible]	9.4	[illegible]	[illegible]	[illegible]	7.5	7.1	6.8	6.5	6.2	5.9	5.7
	5	13.6	[illegible]	11.8	11.1	[illegible]	[illegible]	9.4	8.9	8.5	8.1	7.7	7.4	7.1
	6	[illegible]	15.[illegible]	14.2	[illegible]	[illegible]	11.9	11.3	10.7	10.2	9.7	9.3	8.9	8.6
	7	[illegible]	17.8	16.7	[illegible]	14.7	[illegible]	13.2	12.5	11.9	11.4	10.9	10.4	10.0
	8	[illegible]	[illegible]	19.1	17.9	[illegible]	15.9	15.1	14.3	13.7	13.0	12.5	12.0	11.5
	9	24.9	23.1	[illegible]	[illegible]	19.0	18.0	17.0	16.2	15.4	14.7	14.1	13.5	12.9
	10	27.8	[illegible]	24.0	[illegible]	21.2	20.0	19.0	18.0	17.1	16.4	15.6	15.0	14.4
	11	[illegible]	28.5	26.5	24.9	[illegible]	22.1	20.9	19.9	18.9	18.0	17.3	16.5	15.9
	12	33.[illegible]	31.2	[illegible]	[illegible]	[illegible]	24.2	22.9	21.7	20.7	19.7	18.9	18.1	17.3
	13	36.6	33.9	31.6	[illegible]	[illegible]	26.2	24.8	23.6	22.4	21.4	20.5	19.6	18.8
	14	[illegible]	[illegible]	34.2	[illegible]	[illegible]	28.3	26.8	25.5	24.2	23.1	22.1	21.2	20.3
	15	[illegible]	[illegible]	[illegible]	34.4	[illegible]	30.5	28.8	27.4	26.0	24.8	23.7	22.7	21.8
	16	45.7	[illegible]	39.4	[illegible]	34.6	32.6	30.8	29.3	27.8	26.5	25.4	24.3	23.3
	17	48.9	[illegible]	[illegible]	39.[illegible]	[illegible]	34.8	32.9	31.2	29.7	28.3	27.0	25.9	24.8
	18	[illegible]	[illegible]	44.7	41.8	[illegible]	36.9	34.9	33.1	31.5	30.0	28.7	27.5	26.3
	19	[illegible]	51.1	47.4	44.3	41.5	39.1	37.0	35.1	33.3	31.8	30.4	29.1	27.9
	20	[illegible]	[illegible]	[illegible]	46.8	[illegible]	41.3	39.1	37.0	35.2	33.5	32.0	30.7	29.4
M	21	[illegible]	57.1	53.0	49.4	[illegible]	[illegible]	41.2	39.0	37.1	35.3	33.7	32.3	30.9
	22	65.6	60.3	[illegible]	[illegible]	[illegible]	45.8	43.3	41.0	38.9	37.1	35.4	33.9	32.5
I	23	69.[illegible]	[illegible]	[illegible]	54.7	[illegible]	48.1	45.4	43.0	40.8	38.9	37.1	35.5	34.0
	24	73.[illegible]	[illegible]	[illegible]	57.4	[illegible]	50.4	47.6	45.0	42.8	40.7	38.9	37.2	35.6
C	25	77.1	[illegible]	[illegible]	60.1	[illegible]	52.8	49.8	47.1	44.7	[illegible]	40.6	38.8	37.2
R	26	81.7	73.8	67.9	[illegible]	[illegible]	55.1	52.0	49.2	46.6	44.4	42.3	40.5	38.8
	27		77.7	71.1	[illegible]	[illegible]	57.6	54.2	51.3	48.6	46.2	44.1	42.2	40.4
O	28		[illegible]	74.5	[illegible]	64.1	60.0	56.5	53.4	50.6	48.1	45.9	43.8	42.0
	29			[illegible]	71.9	66.8	62.5	58.8	55.5	52.6	50.0	47.7	45.5	43.6
V	30			[illegible]	75.1	[illegible]	65.1	61.1	57.7	54.7	51.9	49.5	47.3	45.2
O	31				[illegible]	72.6	67.7	63.5	59.9	56.7	53.9	51.3	49.0	46.9
	32				[illegible]	75.7	70.4	66.0	62.2	58.8	55.8	53.2	50.8	48.6
L	33					79.0	73.2	68.5	64.5	61.0	57.8	55.0	52.5	50.2
	34					[illegible]	76.2	71.1	66.8	63.1	59.9	56.9	54.3	51.9
T	35						79.3	73.8	69.2	65.3	61.9	58.9	56.1	53.6
	36						82.9	76.6	71.7	67.6	64.0	60.8	57.9	55.4
	37							79.6	74.3	69.9	66.1	62.8	59.8	57.1
R	38							83.1	77.0	72.3	68.3	64.8	61.7	58.9
	39								79.9	74.8	70.5	66.8	63.6	60.7
E	40								83.2	77.4	72.8	68.9	65.5	62.5
A	41									80.2	75.2	71.1	67.5	64.3
	42									83.4	77.7	73.3	69.5	66.2
D	43										80.4	75.6	71.6	68.1
	44										83.5	78.0	73.8	70.1
I	45											80.6	76.0	72.1
N	46											83.6	78.3	74.2
	47												80.9	76.3
G	48												83.7	78.6
	49													81.0
	50													83.8
	51													
	52													
	53													
	54													
	55													
	56													
	57													
	58													
	59													
	60													
	61													
	62													
	63													
	64													
	65													
	66													
	67													
	68													
	69													

TABLE [illegible] WATER [illegible]

COOLING TIME IN [illegible] ---
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 31.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	-30	-20	-10							
	WATER POTENTIAL, NEGATIVE BARS												
1	[illegible]	2.4	2.3	2.1	2.0	1.9	1.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.6	[illegible]	[illegible]	3.1	[illegible]	[illegible]	2.8
3	[illegible]	[illegible]	6.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	4.7	4.5	4.3	4.2
4	[illegible]	[illegible]	[illegible]	[illegible]	8.2	7.7	7.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	12.4	11.6	10.9	[illegible]	9.7	9.2	[illegible]	[illegible]	7.9	[illegible]	7.3	[illegible]
6	16.[illegible]	14.9	13.9	13.1	12.3	11.6	11.0	10.5	10.0	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	17.4	16.3	15.3	14.4	12.6	12.9	12.2	11.7	11.1	[illegible]	10.2	[illegible]
8	21.[illegible]	20.0	18.7	17.5	16.5	15.6	14.7	14.0	13.3	12.7	[illegible]	11.7	11.2
9	24.[illegible]	22.6	21.1	19.8	18.6	17.6	[illegible]	15.8	[illegible]	14.4	13.7	[illegible]	12.6
10	[illegible]	25.2	23.5	22.0	20.7	19.6	18.5	17.6	[illegible]	16.0	[illegible]	[illegible]	14.1
11	[illegible]	27.8	[illegible]	24.3	[illegible]	21.6	20.4	19.4	18.5	[illegible]	16.9	16.1	[illegible]
12	32.[illegible]	30.5	[illegible]	26.6	[illegible]	23.6	22.3	[illegible]	20.2	[illegible]	18.4	17.7	16.9
13	[illegible]	33.1	30.9	28.9	[illegible]	25.6	24.3	[illegible]	21.9	20.9	20.0	19.2	18.4
14	[illegible]	35.8	33.4	31.2	29.4	[illegible]	26.2	24.9	23.7	[illegible]	21.6	[illegible]	[illegible]
15	41.6	38.5	35.9	33.6	31.6	[illegible]	28.2	26.7	25.4	24.2	23.2	[illegible]	21.3
16	44.6	41.3	38.4	35.9	33.8	31.8	30.1	28.6	27.2	[illegible]	[illegible]	[illegible]	[illegible]
17	47.7	44.1	41.[illegible]	38.3	36.0	33.9	32.1	30.4	[illegible]	27.6	[illegible]	25.3	24.2
18	[illegible]	46.9	[illegible]	40.8	38.3	36.0	34.1	32.3	30.7	[illegible]	28.0	26.8	[illegible]
19	[illegible]	49.8	46.3	[illegible]	40.5	38.2	36.1	[illegible]	[illegible]	31.0	[illegible]	[illegible]	27.2
20	57.2	52.7	48.9	45.7	42.8	[illegible]	38.1	36.1	[illegible]	[illegible]	[illegible]	[illegible]	28.7
M 21	[illegible]	55.7	51.6	[illegible]	45.2	[illegible]	40.2	38.1	36.2	[illegible]	[illegible]	[illegible]	30.2
22	63.6	58.7	54.4	50.7	[illegible]	[illegible]	[illegible]	40.0	38.[illegible]	[illegible]	34.6	33.1	31.7
I 23	[illegible]	61.8	57.2	53.3	49.9	46.9	44.3	41.9	39.8	37.9	36.2	[illegible]	[illegible]
24	70.[illegible]	65.0	60.0	55.9	52.3	[illegible]	46.4	43.9	41.7	39.7	37.9	36.3	[illegible]
C 25	74.7	68.2	63.0	58.5	[illegible]	51.4	48.5	45.9	[illegible]	41.5	[illegible]	[illegible]	36.3
R 26	78.[illegible]	71.6	66.0	[illegible]	57.2	53.7	50.6	47.9	45.5	43.3	41.3	[illegible]	37.8
27	[illegible]	75.2	[illegible]	64.0	[illegible]	56.0	52.8	49.9	47.4	45.1	43.0	41.1	9.4
O 28		79.0	72.3	66.8	62.3	58.4	55.0	[illegible]	49.3	46.9	44.7	[illegible]	40.9
29		83.5	[illegible]	69.8	64.9	[illegible]	[illegible]	[illegible]	51.3	48.7	46.5	44.4	42.5
V 30			79.2	72.8	67.6	63.3	59.5	[illegible]	53.2	[illegible]	48.2	46.1	44.1
O 31			83.4	76.0	70.4	65.8	61.8	58.3	[illegible]	52.5	50.0	[illegible]	45.7
32				79.4	73.3	68.4	64.1	60.5	57.2	54.4	51.8	[illegible]	[illegible]
L 33				83.3	76.3	71.0	66.5	62.7	59.3	[illegible]	[illegible]	51.1	48.9
34					79.6	73.8	69.0	[illegible]	61.4	58.2	55.4	[illegible]	50.6
T 35					83.3	76.6	71.5	67.2	63.5	[illegible]	[illegible]	[illegible]	[illegible]
36						[illegible]	74.2	69.6	65.7	[illegible]	[illegible]	[illegible]	[illegible]
37						83.2	76.9	72.0	67.9	64.2	61.0	[illegible]	[illegible]
R 38							79.9	74.5	70.1	66.3	[illegible]	[illegible]	[illegible]
39							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E 40							[illegible]	80.0	74.9	70.6	[illegible]	[illegible]	[illegible]
A 41								[illegible]	77.4	[illegible]	[illegible]	[illegible]	[illegible]
42								[illegible]	80.1	[illegible]	71.1	[illegible]	[illegible]
D 43								[illegible]	83.1	77.6	73.2	[illegible]	[illegible]
44									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I 45									[illegible]	83.1	[illegible]	[illegible]	69.9
N 46										[illegible]	[illegible]	75.7	71.9
47											[illegible]	[illegible]	73.9
G 48											[illegible]	[illegible]	[illegible]
49											[illegible]	83.0	78.1
50											[illegible]	[illegible]	[illegible]
51													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 32.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	[illegible]	2.4	[illegible]	2.1	[illegible]	[illegible]	[illegible]	1.7	1.6	1.5	1.5	1.4	1.4
	5.2	4.[illegible]	4.5	4.[illegible]	4.[illegible]	3.8	[illegible]	[illegible]	3.2	[illegible]	2.9	[illegible]	2.7
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.6	5.3	[illegible]	4.8	4.6	4.4	4.2	4.1
4	[illegible]	9.7	9.0	8.5	8.0	7.5	7.1	6.8	6.5	[illegible]	[illegible]	5.7	5.4
	13.0	12.1	11.3	10.6	10.0	9.4	[illegible]	[illegible]	8.1	[illegible]	7.4	7.1	[illegible]
	[illegible]	14.6	13.6	12.8	12.0	11.4	10.8	10.2	9.7	9.3	8.9	8.5	[illegible]
7	18.4	17.1	15.9	14.9	14.1	13.3	12.6	12.0	11.4	10.9	10.4	10.0	9.6
8	21.1	19.6	18.3	17.1	[illegible]	15.2	14.4	13.7	13.0	12.5	11.9	11.4	11.0
[illegible]	[illegible]	22.1	20.6	19.3	18.2	17.2	16.3	15.4	14.7	14.0	13.4	12.9	12.3
1[illegible]	26.5	24.6	[illegible]	21.5	20.2	19.1	18.1	17.2	16.4	15.6	14.9	14.3	13.7
11	29.3	27.2	25.3	[illegible]	22.3	21.1	20.0	19.0	18.0	17.2	16.5	15.8	15.1
12	32.1	29.8	27.7	26.0	24.4	23.1	21.8	20.7	19.7	18.8	18.0	17.2	16.6
[illegible]	34.9	32.4	30.2	28.2	26.5	25.0	[illegible]	22.5	21.4	20.4	19.5	18.7	18.0
14	37.8	35.0	32.6	30.5	28.7	27.0	25.6	24.3	23.1	22.1	21.1	20.2	19.4
[illegible]	40.7	37.6	35.0	32.8	30.8	29.1	27.5	26.1	24.8	23.7	22.6	21.7	20.8
16	43.6	40.3	37.5	35.1	33.0	31.1	29.4	27.9	26.6	25.3	24.2	23.2	22.2
17	46.5	43.0	40.0	37.4	[illegible]	33.1	31.3	29.7	28.3	27.0	25.8	24.7	23.7
[illegible]	49.5	45.8	42.6	39.8	37.3	35.2	33.3	31.6	30.0	28.6	27.3	26.2	25.1
19	52.6	48.6	45.1	42.2	[illegible]	37.3	35.2	33.4	31.8	30.3	28.9	27.7	26.6
[illegible]	55.7	[illegible]	47.7	44.6	41.8	39.4	37.2	[illegible]	[illegible]	32.0	30.5	29.2	28.0
M 21	58.9	54.3	50.3	47.0	44.0	41.5	39.2	37.1	35.3	33.6	32.1	30.7	29.5
[illegible]	62.1	57.2	53.0	49.4	46.3	43.6	41.2	39.0	37.1	35.3	33.7	[illegible]	[illegible]
[illegible]	[illegible]	60.2	55.7	51.9	48.6	45.8	43.2	40.9	38.9	37.0	35.4	33.8	32.4
24	68.9	[illegible]	[illegible]	54.4	51.0	47.9	45.2	42.8	[illegible]	38.7	37.0	35.4	33.9
[illegible]	[illegible]	66.3	61.3	57.0	53.3	50.1	47.3	44.[illegible]	42.5	40.5	38.6	36.9	35.4
F 26	[illegible]	[illegible]	64.2	59.6	55.7	52.3	49.4	46.7	44.3	42.2	40.3	[illegible]	36.9
27	80.4	72.9	67.1	[illegible]	58.2	54.6	51.5	48.7	46.2	44.0	41.9	40.1	38.4
28		76.5	70.2	65.0	60.6	[illegible]	53.6	50.7	48.1	45.7	43.6	41.7	39.9
[illegible]		80.3	73.3	67.8	63.2	59.2	55.7	52.7	50.0	47.5	45.3	43.3	41.5
[illegible]		85.1	76.7	70.7	65.8	61.6	57.9	54.7	51.9	49.3	47.0	44.9	43.0
1			80.3	73.7	68.4	64.0	60.1	56.8	53.8	51.1	[illegible]	46.5	44.6
[illegible]			84.6	76.8	71.1	66.4	62.4	58.9	55.7	53.0	50.5	48.2	46.1
[illegible] 33				80.2	74.0	68.9	64.7	61.0	57.7	54.8	52.2	49.8	47.7
4				84.2	76.9	71.5	67.0	63.1	59.7	56.7	54.0	51.5	49.3
[illegible]					80.1	74.2	[illegible]	65.3	61.8	58.6	[illegible]	53.2	50.9
[illegible]					[illegible]	77.1	71.9	67.6	63.8	60.5	57.6	54.9	[illegible]
37						80.1	[illegible]	[illegible]	65.9	62.5	[illegible]	56.6	54.1
R [illegible]						83.5	77.2	72.3	68.1	[illegible]	61.2	58.4	55.8
[illegible]							[illegible]	74.7	70.3	66.5	63.1	60.1	57.4
F 4[illegible]							83.3	77.3	72.6	68.5	65.0	61.9	59.1
A 41								80.0	74.9	70.7	67.0	63.7	[illegible]
42								83.1	77.4	72.8	69.0	65.6	62.5
I 43									[illegible]	75.1	71.0	67.4	[illegible]
44									82.9	77.4	73.1	69.4	66.1
I 4[illegible]										79.9	75.3	71.3	67.9
N 4[illegible]										82.7	77.5	73.3	69.7
47											79.9	75.4	71.6
[illegible] 48											82.5	77.6	73.6
[illegible]												79.9	75.6
[illegible]												[illegible]	77.6
[illegible]													79.9
[illegible]													82.2
53													85.2
[illegible]													
[illegible]													
[illegible]													
[illegible]													
60													
[illegible]													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 34.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3
	2	4.9	4.6	4.3	4.0	3.8	3.6	3.4	3.2	3.1	2.9	2.8	2.7	2.6
	3	7.4	6.9	6.5	6.1	5.7	5.4	5.1	4.9	4.6	4.4	4.2	4.1	3.9
	4	9.9	9.2	8.6	8.1	7.6	7.2	6.8	6.5	6.2	5.9	5.7	5.4	5.2
	5	12.5	11.6	10.8	10.1	9.6	9.0	8.6	8.1	7.7	7.4	7.1	6.8	6.5
	6	15.0	13.9	13.0	12.2	11.5	10.9	10.3	9.8	9.3	8.9	8.5	8.2	7.8
	7	17.6	16.3	15.2	14.3	13.4	12.7	12.0	11.4	10.9	10.4	9.9	9.5	9.2
	8	20.1	18.7	17.5	16.4	15.4	14.5	13.8	13.1	12.5	11.9	11.4	10.9	10.5
	9	22.7	21.1	19.7	18.5	17.4	16.4	15.5	14.8	14.1	13.4	12.8	12.3	11.8
	10	25.3	23.5	21.9	20.6	19.3	18.3	17.3	16.4	15.6	14.9	14.3	13.7	13.1
	11	28.0	26.0	24.2	22.7	21.3	20.1	19.1	18.1	17.2	16.5	15.7	15.1	14.5
	12	30.6	28.4	26.5	24.8	23.3	22.0	20.9	19.8	18.8	18.0	17.2	16.5	15.8
	13	33.3	30.9	28.8	27.0	25.3	23.9	22.6	21.5	20.5	19.5	18.7	17.9	17.2
	14	36.0	33.4	31.1	29.1	27.4	25.8	24.4	23.2	22.1	21.1	20.1	19.3	18.5
	15	38.8	35.9	33.4	31.3	29.4	27.7	26.3	24.9	23.7	22.6	21.6	20.7	19.9
	16	41.5	38.4	35.8	33.5	31.5	29.7	28.1	26.6	25.3	24.2	23.1	22.1	21.2
	17	44.3	41.0	38.2	35.7	33.5	31.6	29.9	28.4	27.0	25.7	24.6	23.6	22.6
	18	47.2	43.6	40.6	37.9	35.6	33.6	31.7	30.1	28.6	27.3	26.1	25.0	24.0
	19	50.0	46.2	43.0	40.2	37.7	35.5	33.6	31.9	30.3	28.9	27.6	26.4	25.3
	20	52.9	48.9	45.4	42.4	39.8	37.5	35.5	33.6	32.0	30.5	29.1	27.9	26.7
M	21	55.9	51.6	47.9	44.7	42.0	39.5	37.3	35.4	33.7	32.1	30.6	29.3	28.1
	22	58.9	54.3	50.4	47.0	44.1	41.5	39.2	37.2	35.4	33.7	32.2	30.8	29.5
I	23	62.0	57.1	53.0	49.4	46.3	43.6	41.1	39.0	37.1	35.3	33.7	32.3	30.9
	24	65.2	59.9	55.5	51.8	48.5	45.6	43.1	40.8	38.8	36.9	35.3	33.7	32.3
C	25	68.5	62.8	58.1	54.2	50.7	47.7	45.0	42.6	40.5	38.6	36.8	35.2	33.8
R	26	71.8	65.8	60.8	56.6	53.0	49.8	47.0	44.5	42.2	40.2	38.4	36.7	35.2
	27	75.4	68.8	63.5	59.1	55.2	51.9	48.9	46.3	44.0	41.9	39.9	38.2	36.6
O	28	79.2	72.0	66.3	61.6	57.5	54.0	50.9	48.2	45.7	43.5	41.5	39.7	38.0
	29	83.6	75.3	69.2	64.2	59.9	56.2	53.0	50.1	47.5	45.2	43.1	41.2	39.5
V	30		78.8	72.2	66.8	62.3	58.4	55.0	52.0	49.3	46.9	44.7	42.8	40.9
O	31		82.8	75.2	69.5	64.7	60.6	57.1	53.9	51.1	48.6	46.4	44.3	42.4
	32			78.5	72.3	67.2	62.9	59.2	55.9	53.0	50.3	48.0	45.8	43.9
L	33			82.1	75.2	69.8	65.2	61.3	57.9	54.8	52.1	49.6	47.4	45.4
	34				78.3	72.4	67.6	63.4	59.9	56.7	53.8	51.3	49.0	46.9
T	35				81.6	75.1	70.0	65.7	61.9	58.6	55.6	53.0	50.6	48.4
	36					78.0	72.5	67.9	64.0	60.5	57.4	54.6	52.2	49.9
	37					81.1	75.1	70.2	66.1	62.4	59.2	56.4	53.8	51.4
R	38					84.9	77.8	72.6	68.2	64.4	61.1	58.1	55.4	53.0
	39						80.7	75.0	70.4	66.4	62.9	59.8	57.0	54.5
E	40						84.1	77.6	72.7	68.5	64.8	61.6	58.7	56.1
A	41							80.3	75.0	70.6	66.8	63.4	60.4	57.7
	42							83.4	77.4	72.7	68.7	65.2	62.1	59.3
D	43								80.0	75.0	70.7	67.1	63.8	60.9
	44								82.9	77.3	72.8	69.0	65.6	62.5
I	45									79.7	74.9	70.9	67.3	64.2
N	46									82.4	77.1	72.9	69.2	65.9
	47										79.5	74.9	71.0	67.6
G	48										82.0	77.0	72.9	69.4
	49										85.0	79.2	74.9	71.1
	50											81.6	76.9	73.0
	51											84.4	79.0	74.8
	52												81.3	76.8
	53												83.8	78.8
	54													81.0
	55													83.4
	56													
	57													
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COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 35.0

		-60		-40		-20	-10	0			+30			
	1	[illegible]				1.9	1.8							
	2	[illegible]	4.5	[illegible]	3.9	3.7								
	3	[illegible]			[illegible]				[illegible]		4.3		4.0	
	4	[illegible]	9.0	[illegible]	7.9		7.1	6.7	6.4					5.1
	5	[illegible]	11.3	10.6	[illegible]									
	6	[illegible]	13.6	12.7	11.9		10.6	10.1			8.7			7.7
	7	[illegible]	15.9	14.9	14.0	13.1	12.4	[illegible]	11.2		10.2	9.7		
	8	[illegible]	18.3	17.1	16.0	[illegible]	14.2	[illegible]	[illegible]	12.2	[illegible]	11.1		
	9	22 [illegible]	20.6	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	13.7	13.1			[illegible]
	10	24 [illegible]	[illegible]	21.4	20.1	[illegible]	[illegible]	16.9	[illegible]			[illegible]	13.4	
	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.7	[illegible]	[illegible]	[illegible]	14.7	
	12	[illegible]	27.8	[illegible]	[illegible]	22.8	[illegible]	[illegible]	19.4	[illegible]	[illegible]	[illegible]	16.1	[illegible]
	13	[illegible]	30.2	28.1	26.3	[illegible]	[illegible]	[illegible]	21.0	[illegible]	19.1	18.3	[illegible]	[illegible]
	14	[illegible]	32.6	[illegible]	28.5	26.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.7	[illegible]	[illegible]
	15	[illegible]	35.1	32.7	30.6	[illegible]	27.1	25.7	[illegible]	[illegible]	22.1	[illegible]	[illegible]	[illegible]
	16	[illegible]	37.5	[illegible]	32.7	30.7	29.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	17	[illegible]	40.0	37.3	34.9	[illegible]	[illegible]	29.2	27.7	26.4	[illegible]	[illegible]	[illegible]	22.1
	18	[illegible]	42.6	39.6	[illegible]	[illegible]	[illegible]	[illegible]	29.4	[illegible]	[illegible]	[illegible]	24.4	23.4
	19	48 [illegible]	45.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	20	[illegible]	47.7	[illegible]	41.4	[illegible]	[illegible]	34.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.1
M	21	[illegible]	50.3	46.7	43.7	41.0	[illegible]	[illegible]	[illegible]	[illegible]	32.9	31.3	[illegible]	[illegible]
	22	57.4	53.0	[illegible]	45.9	43.1	40.5	38.3	[illegible]		34.5	[illegible]	31.4	30.1	28.8
I	23	[illegible]	55.7	51.6	48.2	[illegible]	[illegible]	[illegible]	38.1	[illegible]	34.5	32.9	[illegible]	30.2
	24	63.5	58.4	54.1	50.5	47.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31.6
C	25	66.[illegible]	61.2	56.7	52.8	[illegible]	[illegible]	43.9	41.6	39.5	37.7	[illegible]	4.4	33.0
R	26	[illegible]	64.1	59.3	55.2	51.7	48.6	[illegible]	43.4	41.2	[illegible]	37.5	35.9	[illegible]
	27	73.2	[illegible]	61.9	57.6	[illegible]	50.6	47.8	45.2	42.9	40.9	39.0	[illegible]	[illegible]
[illegible]	28	[illegible]	[illegible]	64.6	60.0	56.1	52.7	49.7	[illegible]	[illegible]	[illegible]	40.6	[illegible]	[illegible]
	29	[illegible]	73.1	[illegible]	[illegible]	58.4	[illegible]	51.7	48.9	46.4	[illegible]	[illegible]	40.3	[illegible]
V	30	[illegible]	76.4	70.1	65.0	60.7	56.9	53.6	50.7	48.1	[illegible]	43.7	41.7	[illegible]
[illegible]	31		79.9	73.1	67.6	63.0	59.1	[illegible]	[illegible]	49.9	47.4	[illegible]	[illegible]	41.4
	32		84.0	76.1	70.3	65.4	61.3	57.7	54.5	51.7	49.1	[illegible]	44.7	[illegible]
L	33			[illegible]	73.0	[illegible]	[illegible]	59.7	[illegible]	[illegible]		46.4	46.	[illegible]
	34			83.0	75.9	70.4	65.8	[illegible]	[illegible]		52.5	[illegible]	[illegible]	[illegible]
T	35				78.9	[illegible]	68.1	63.9	[illegible]	57.1	[illegible]	[illegible]	[illegible]	[illegible]
	36				82.2	75.6	70.5	66.1	[illegible]	56.9	56.	[illegible]	[illegible]	[illegible]
	37					78.5	72.9	[illegible]	[illegible]	60.8	57.7	[illegible]	52.4	50.2
F	38					81.6	[illegible]	[illegible]	[illegible]	62.7	59.5	[illegible]	[illegible]	[illegible]
	39						78.1	[illegible]	[illegible]	[illegible]	61.	[illegible]	[illegible]	[illegible]
E	40						81.0	[illegible]	74.6	[illegible]	63.1	[illegible]	[illegible]	[illegible]
A	41						84.3	77.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	42							80.5	[illegible]	[illegible]	66.9	[illegible]	[illegible]	[illegible]
D	43							83.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	44								[illegible]	75.0	[illegible]	67.1	[illegible]	[illegible]
I	45								82.8	77.2	[illegible]	[illegible]	[illegible]	[illegible]
N	46								[illegible]	[illegible]	[illegible]	[illegible]	67.3	64.2
	47								[illegible]	[illegible]	77.0	[illegible]	[illegible]	[illegible]
G	48								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.5
	49										81.7	[illegible]	[illegible]	[illegible]
	50										[illegible]	[illegible]	74.6	[illegible]
	51													
	52													
	53													76.4
	54													
	55													[illegible]
	56													
	57													
	58													
	59													
	60													
	61													
	62													
	63													
	64													
	65													
	66													
	67													
	68													
	69													
	70													

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 36.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	1	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2
	2	4.7	4.4	4.1	3.9	3.6	3.4	3.3	3.1	3.0	2.8	2.7	2.6	2.5
	3	7.1	6.6	6.2	5.8	5.5	5.2	4.9	4.7	4.4	4.2	4.1	3.9	3.7
	4	9.5	8.8	8.3	7.7	7.3	6.9	6.5	6.2	5.9	5.7	5.4	5.2	5.0
	5	11.9	11.1	10.3	9.7	9.1	8.6	8.2	7.8	7.4	7.1	6.8	6.5	6.2
	6	14.3	13.[illegible]	12.4	11.7	11.0	10.4	[illegible]	9.4	8.9	8.5	8.1	7.8	[illegible]
	7	[illegible].8	[illegible].6	[illegible]	13.7	[illegible]	[illegible].1	11.5	10.9	10.4	[illegible]	9.5	9.1	[illegible]
	8	[illegible]	17.[illegible]	16.7	15.[illegible]	14.7	13.9	13.2	12.5	11.9	11.4	10.9	10.4	10.0
	9	21.7	[illegible].2	[illegible]	17.[illegible]	16.6	15.7	14.9	14.1	13.4	12.8	[illegible]	11.8	11.3
	10	[illegible]	[illegible]	21.[illegible]	19.7	18.5	17.5	[illegible]	15.7	15.0	14.3	13.7	13.1	12.6
	11	26.7	24.[illegible]	23.1	21.7	20.4	19.3	18.2	17.3	16.5	15.7	15.1	14.4	13.8
	12	29.2	27.1	25.3	23.7	22.3	21.0	19.9	18.9	18.0	17.2	16.4	15.8	15.1
	13	31.[illegible]	29.5	[illegible]	[illegible]	24.2	22.9	21.6	20.5	19.6	18.7	17.8	17.1	16.4
	14	34.4	31.9	[illegible]	[illegible]	26.1	24.7	23.4	22.2	21.1	20.1	19.3	18.4	17.7
	15	37	34.3	[illegible]	[illegible]	28.1	26.5	25.1	23.8	22.7	21.6	20.7	19.8	19.0
	16	[illegible]	[illegible].7	34.2	[illegible]	30.0	[illegible]	[illegible]	25.5	24.2	23.1	22.1	21.2	20.3
	17	[illegible]	39.1	[illegible]	34.1	32.0	30.2	28.6	27.1	25.8	24.6	23.5	22.5	21.6
	18	44.9	41.[illegible]	[illegible].7	[illegible]	34.0	32.0	30.3	[illegible]	27.4	26.1	24.9	23.9	22.9
	19	47.6	44.0	[illegible]	[illegible]	36.0	33.9	32.1	30.4	28.9	27.6	26.4	25.3	24.2
	20	[illegible]	[illegible]	43.3	[illegible]	38.0	35.8	33.9	32.1	30.5	29.1	27.8	26.6	25.5
M	21	[illegible]	49.1	45.6	[illegible]	40.0	37.7	[illegible]	33.8	[illegible].1	30.6	29.3	28.0	26.9
	22	[illegible]	[illegible]	[illegible]	[illegible]	42.0	39.6	37.4	35.5	33.7	32.2	30.7	29.4	28.2
I	23	58.9	54.3	[illegible]	47.0	44.1	41.5	39.2	37.2	35.4	33.7	32.2	[illegible]	29.5
	24	[illegible]	56.9	[illegible]	49.[illegible]	46.2	43.5	41.1	38.9	37.0	35.2	33.7	32.2	30.9
C	25	[illegible]	[illegible]	[illegible]	51.5	[illegible]	[illegible]	42.9	40.6	38.6	[illegible]	35.1	33.6	32.2
R	26	67.9	[illegible]	57.8	[illegible]	[illegible]	47.4	44.8	42.4	40.3	[illegible]	36.6	35.0	33.6
	27	71.1	[illegible]	[illegible]	56.1	52.5	49.4	46.6	44.1	41.9	39.9	38.1	[illegible]	34.9
O	28	74.[illegible]	[illegible]	[illegible]	[illegible]	54.7	51.4	48.5	45.9	43.6	[illegible]	39.6	37.9	36.3
	29	[illegible]	71.1	65.[illegible]	60.9	56.9	[illegible]	50.4	47.7	45.3	43.1	41.1	39.3	37.7
V	30	[illegible]	74.[illegible]	[illegible]	[illegible]	59.1	[illegible]	52.3	49.5	47.0	44.7	42.6	[illegible]	39.1
O	31		77.4	71.0	[illegible]	61.4	57.6	54.3	51.3	48.7	46.3	44.2	42.2	40.4
	32		81.0	73.9	[illegible]	63.7	59.7	56.2	53.2	50.4	47.9	45.7	43.7	41.8
I	33		[illegible]	76.9	71.0	66.0	61.9	[illegible]	55.0	52.1	49.6	47.3	45.2	43.3
	34			[illegible]	73.7	68.4	64.0	60.2	56.9	53.9	51.2	[illegible]	46.7	44.7
T	35			83.9	[illegible]	70.9	66.3	62.3	[illegible]	55.7	52.9	50.4	48.1	46.1
	36				79.5	73.5	[illegible]	64.3	60.7	57.5	54.6	52.0	49.7	47.5
	37				82.8	76.1	70.9	66.5	62.6	59.3	56.3	53.6	51.2	49.0
R	38					78.9	73.3	68.6	64.6	61.1	58.0	55.2	52.7	[illegible]
	39					82.0	75.8	70.8	66.6	63.0	59.8	56.9	54.2	51.9
E	40						78.4	73.1	68.7	64.9	61.5	58.5	55.8	53.4
A	41						81.2	75.5	70.8	[illegible]	[illegible]	60.2	57.4	[illegible]
	42						84.5	77.9	73.0	[illegible]	65.1	61.9	59.[illegible]	[illegible]
I	43							[illegible]	75.2	70.8	[illegible]	63.6	60.6	57.9
	44							[illegible]	77.5	[illegible]	68.8	65.3	[illegible]	59.4
I	45								80.0	75.0	70.7	67.1	63.8	60.9
N	46								82.7	77.2	72.7	68.9	[illegible]	62.5
	47									79.5	74.7	70.7	67.2	64.1
G	48									82.0	76.8	72.6	68.9	65.7
	49									84.9	79.0	74.5	70.7	67.3
	50										81.4	76.5	72.5	69.0
	51										84.0	78.6	74.3	70.7
	52											80.8	76.2	72.4
	53											[illegible]	78.2	74.2
	54												80.3	76.0
	55												82.6	77.9
	56												85.4	79.9
	57													82.0
	58													84.4
	61													
	62													
	63													
	64													
	65													
	66													
	67													
	68													
	69													

11	26.1	[illegible]	[illegible]	[illegible]	[illegible]
17	41.2	36.2	35.6	33.3	31.3
[illegible]	[illegible]	40.6	37.	[illegible]	[illegible]
[illegible]	51.9	47.9	44.6	41.6	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	74.3	69.	[illegible]
A 41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 30.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 38.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.3	2.1	2.0	1.8	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2
	2	4.5	4.2	3.9	3.7	3.5	3.3	3.1	3.0	2.8	2.7	2.6	2.5	2.4
	3	6.8	6.3	5.9	5.6	5.2	4.9	4.7	4.5	4.2	4.1	3.9	3.7	3.6
	4	9.1	8.5	7.9	7.4	7.0	6.6	6.3	6.0	5.7	5.4	5.2	5.0	4.8
	5	11.4	10.6	9.9	9.3	8.8	8.3	7.8	7.5	7.1	6.8	6.5	6.2	6.0
	6	13.7	12.8	11.9	11.2	10.5	9.9	9.4	9.0	8.5	8.2	7.8	7.5	7.2
	7	16.1	14.9	13.9	13.1	12.3	11.6	11.0	10.5	10.0	9.5	9.1	8.7	8.4
	8	18.4	17.1	16.0	15.0	14.1	13.3	12.6	12.0	11.4	10.9	10.4	10.0	9.6
	9	20.8	19.3	18.0	16.9	15.9	15.0	14.2	13.5	12.9	12.3	11.8	11.3	10.8
	10	23.1	21.5	20.0	18.8	17.7	16.7	15.8	15.0	14.3	13.7	13.1	12.5	12.0
	11	25.5	23.7	22.1	20.7	19.5	18.4	17.4	16.6	15.8	15.1	14.4	13.8	13.3
	12	27.9	25.9	24.2	22.7	21.3	20.1	19.1	18.1	17.2	16.5	15.7	15.1	14.5
	13	30.4	28.2	26.3	24.6	23.2	21.9	20.7	19.7	18.7	17.9	17.1	16.4	15.7
	14	32.8	30.4	28.4	26.6	25.0	23.6	22.3	21.2	20.2	19.3	18.4	17.7	16.9
	15	35.3	32.7	30.5	28.5	26.8	25.3	24.0	22.8	21.7	20.7	19.8	18.9	18.2
	16	37.8	35.0	32.6	30.5	28.7	27.1	25.6	24.3	23.2	22.1	21.1	20.2	19.4
	17	40.3	37.3	34.8	32.5	30.6	28.8	27.3	25.9	24.7	23.5	22.5	21.5	20.7
	18	42.8	39.7	36.9	34.5	32.5	30.6	29.0	27.5	26.2	25.0	23.9	22.8	21.9
	19	45.4	42.0	39.1	36.6	34.4	32.4	30.7	29.1	27.7	26.4	25.2	24.2	23.2
	20	48.0	44.4	41.3	38.6	36.3	34.2	32.3	30.7	29.2	27.8	26.6	25.5	24.4
M	21	50.6	46.8	43.5	40.7	38.2	36.0	34.0	32.3	30.7	29.3	28.0	26.8	25.7
	22	53.3	49.2	45.8	42.8	40.1	37.8	35.8	33.9	32.2	30.7	29.4	28.1	27.0
I	23	56.0	51.7	48.0	44.9	42.1	39.6	37.5	35.5	33.8	32.2	30.8	29.4	28.2
	24	58.8	54.2	50.3	47.0	44.1	41.5	39.2	37.2	35.3	33.7	32.2	30.8	29.5
C	25	61.6	56.7	52.6	49.1	46.0	43.3	40.9	38.8	36.9	35.2	33.6	32.1	30.8
R	26	64.4	59.3	55.0	51.3	48.0	45.2	42.7	40.5	38.5	36.6	35.0	33.5	32.1
	27	67.4	61.9	57.3	53.4	50.1	47.1	44.5	42.1	40.0	38.1	36.4	34.8	33.4
O	28	70.4	64.6	59.8	55.7	52.1	49.0	46.3	43.8	41.6	39.6	37.8	36.2	34.7
	29	73.6	67.3	62.2	57.9	54.2	50.9	48.1	45.5	43.2	41.1	39.3	37.6	36.0
V	30	76.9	70.1	64.7	60.2	56.3	52.9	49.9	47.2	44.8	42.7	40.7	38.9	37.3
O	31	80.4	73.1	67.5	62.5	58.4	54.8	51.7	48.9	46.4	44.2	42.2	40.3	38.6
	32	84.6	76.1	69.9	64.8	60.5	56.8	53.5	50.7	48.1	45.7	43.6	41.7	40.0
L	33		79.3	72.6	67.2	62.7	58.8	55.4	52.4	49.7	47.3	45.1	43.1	41.3
	34		82.9	75.4	69.7	64.9	60.9	57.3	54.2	51.4	48.9	46.6	44.5	42.6
T	35			78.4	72.2	67.2	62.9	59.2	55.9	53.0	50.4	48.1	45.9	44.0
	36			81.6	74.9	69.5	65.0	61.2	57.7	54.7	52.0	49.6	47.4	45.3
	37				77.6	71.9	67.2	63.1	59.6	56.4	53.6	51.1	48.8	46.7
R	38				80.6	74.4	69.4	65.1	61.4	58.2	55.2	52.6	50.2	48.1
	39				83.9	76.9	71.6	67.2	63.3	59.9	56.9	54.2	51.7	49.5
E	40					79.7	73.9	69.2	65.2	61.7	58.5	55.7	53.2	50.9
A	41					82.6	76.3	71.4	67.1	63.4	60.2	57.3	54.6	52.3
	42						78.9	73.5	69.1	65.3	61.9	58.9	56.1	53.7
D	43						81.6	75.8	71.1	67.1	63.6	60.5	57.6	55.1
	44						84.8	78.2	73.2	69.0	65.3	62.1	59.2	56.5
I	45							80.7	75.3	70.9	67.1	63.7	60.7	58.0
N	46							83.5	77.5	72.9	68.9	65.4	62.3	59.5
	47								79.9	74.9	70.7	67.1	63.8	60.9
G	48								82.4	77.0	72.6	68.8	65.4	62.4
	49									79.2	74.5	70.5	67.1	63.9
	50									81.5	76.5	72.3	68.7	65.5
	51									84.2	78.6	74.2	70.4	67.0
	52										80.8	76.0	72.1	68.6
	53										83.2	78.0	73.8	70.2
	54											80.1	75.6	71.9
	55											82.3	77.5	73.5
	56											84.9	79.4	75.3
	57												81.5	77.0
	58												83.8	78.9
	59													80.8
	60													82.9
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PREDICTED WATER POTENTIAL

METER TEMPERATURE, CENTIGRADE --- 40.0

WATER POTENTIAL, NEGATIVE BARS

					1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1
							3.0	2.8	2.7	2.6	2.5	2.4	2.3
						4.7	4.5	4.3	4.1	3.9	3.7	3.6	3.4
					6.7	6.3	6.0	5.7	5.4	5.2	5.0	4.8	4.6
							7.5	7.1	6.8	6.5	6.2	6.0	5.7
			11.		10.1		9.0	8.6	8.2	7.8	7.5	7.2	6.9
					11.8	11.1	10.6	10.0	[illegible]	9.1	8.7	8.4	.
							12.1	11.5	10.9	10.4	10.0	9.6	9.2
					15.2	14.4		12.9	12.3	11.8	11.3	10.8	10.4
			19.2				15.2	14.4	13.7	13.1	12.5	12.0	11.5
			21					15.9	15.1	14.4	13.8	13.2	12.7
								17.3	16.5	15.8	15.1	14.5	13.9
			1		22.2	20.9	19.8	18.8	17.9	17.1	16.4	15.7	15.1
							21.4	20.3	19.3	18.5	17.7	16.9	16.2
							23.0	21.8	20.8	19.8	[illegible]	18.1	17.4
				29.2	27.5		24.5	23.3	22.2	21.2	20.2	19.4	18.6
17		35.7	.2	31.1		27.6	26.1	24.8	23.6	[illegible]	21.5	20.6	19.8
		37.9			31.0	29.3	27.7	26.3	25.0	23.9	22.8	21.9	21.0
19	.2		4	35.0	32.9	31.0	29.3	27.8	26.5	25.3	24.2	23.1	22.2
		40.4			34.7	32.7	30.9	29.4	27.9	26.6	25.5	24.4	23.4
		44.7			36.5	34.4	32.6	30.9	29.4	28.0	26.8	25.7	24.6
	.6			40.8		36.1	34.2	[illegible]	30.9	29.4	[illegible]	26.9	25.8
I	.4				40.2		35.8	34.0	32.3	30.8	29.4	28.2	27.0
	.9				42.1	39.6	37.5	35.5	33.8	32.2	[illegible]	29.5	28.3
			.2	46.9	44.0	41.4	39.1	37.1	[illegible]	33.6	32.1	30.7	29.5
			.4	48.9	45.9	[illegible]	40.8	38.7	36.8	35.0	33.5	32.0	30.7
	64.0	58.9		51.0	47.8		42.5	40.3	38.3	36.5	[illegible]	33.3	32.0
	.3	61.4	56.9	53.1	49.7	46.8	44.2	41.9	39.8	37.9	36.2	34.6	33.2
	.7	64.0	59.2		51.7	48.6	45.9	43.5	41.3	39.3	37.6	[illegible]	34.4
V	.6		.6	57.3	53.6	50.4	47.6	45.1	[illegible]	[illegible]	38.9	37.2	35.7
31	.8	69.2	.9	59.5		52.3	49.3	46.7	44.4	42.2	40.3	38.6	37.0
		72.0	.4	61.7	57.7	[illegible]	51.1	48.4	45.9	43.7	41.7	[illegible]	38.2
		74.8			59.7	56.1	52.8	50.0	47.5	45.2	43.1	41.2	39.5
34		77.8	71.4	66.2	61.8	58.0	54.6	51.7	49.0	46.7	44.5	42.6	[illegible]
		81.1	.1	68.5	63.9		56.4	53.4	50.6	48.2	45.9	43.9	42.0
			.8	70.9	66.0	61.9	58.3	55.1	52.2	49.7	47.3	45.3	43.3
37			79		68.2	63.9	60.1	56.8	53.8	51.2	48.8	[illegible]	44.6
			83		70.5	65.9	62.0	58.5	55.4	52.7	50.2	48.0	45.9
					72.8			[illegible]	57.1	54.2	51.7	49.4	47.2
40					75.2	70.1	65.8	62.0	58.7	55.8	53.1	50.8	48.6
				85.0	77.7	72.3	67.7	63.8	60.4	57.4	54.6	52.2	49.9
					80.3	74.5	69.7	[illegible]	62.1	[illegible]	56.1	53.6	51.2
D 43					83.2	76.8	71.8	67.5	63.8	60.6	57.6	55.0	52.6
						79.2	73.9	69.4	65.6	62.2	59.1	56.4	53.9
							76.1	71.4	67.3	63.8	60.7	57.9	55.3
						85.0	78.3	73.3	69.1	65.5	62.2	59.3	56.7
							80.7	75.4	71.0	67.2	[illegible]	60.8	58.1
							[illegible]	[illegible]	72.9	68.9	65.4	62.3	59.5
49								79.8	74.8	70.6	67.0	63.8	60.9
								82.2	76.8	72.4	68.7	65.3	62.3
								[illegible]	78.9	74.3	70.3	[illegible]	63.8
									81.1	76.2	72.0	68.4	65.2
									[illegible]	78.1	73.8	70.0	66.7
54										80.2	75.6	71.7	68.2
										82.4	77.4	73.3	69.8
										85.0	79.4	75.0	71.3
											81.4	76.8	72.9
											83.7	78.6	74.6
												80.5	76.2
												82.6	78.0
61												85.1	79.8
													81.7
													83.8

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PREDICTED WATER POTENTIAL

LINK TIME IN [illegible] ---------- [illegible]
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 1.0

OFFSET FROM ZERO IN MICROVOLTS

	-[illegible]	-[illegible]	-4	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	WATER POTENTIAL, NEGATIVE BARS												
1	6.0	5.7	[illegible]	5.2	[illegible]	4.8	4.6	4.5	4.3	4.2	4.0	3.9	3.8
2	12.2	11.6	11.1	10.6	10.2	9.8	9.4	9.0	8.7	8.4	8.1	7.9	7.6
3	18.6	17.7	[illegible]	16.1	15.5	14.8	14.3	13.7	13.2	[illegible]	12.3	11.9	11.6
4	25.2	24.0	[illegible]	21.8	20.9	20.1	19.3	18.5	17.9	17.2	16.6	16.1	15.6
5	32.2	30.6	[illegible]	27.8	26.6	25.4	24.4	23.5	22.6	21.8	21.1	20.4	19.7
6	39.5	37.5	35.6	33.9	32.4	31.0	29.8	28.6	27.5	26.5	25.6	24.7	23.9
7	47.4	44.8	42.5	40.4	38.6	36.9	35.3	33.9	[illegible]	31.4	30.3	29.2	28.2
8	56.1	52.8	49.9	47.3	45.1	43.0	41.1	39.4	37.9	36.4	35.1	33.9	32.7
9	66.1	61.7	58.0	54.8	52.0	[illegible]	47.3	45.3	[illegible]	41.7	40.1	38.7	37.3
10		72.8	67.5	63.3	59.7	56.6	53.9	51.5	49.3	47.2	45.4	43.7	42.2
11				73.9	[illegible]	64.6	61.2	58.2	55.6	53.2	51.0	49.0	47.2
12						74.8	69.8	65.9	62.5	59.6	57.0	54.7	52.6
13								75.7	70.7	66.9	63.7	60.9	58.3
14										76.5	71.6	67.9	64.7
15												77.2	72.4
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[illegible]
PSYCHROMETER TEMPERATURE, [illegible]

1									4				
	11.7	[illegible]1											7[illegible]
	17.8				14.7	14.1							
4	24.1	22				19.0		17.5		16[illegible]			
	30.7	[illegible]1				24.1							
	37.6				30.7								
7	45.0		40.2	38.2									
				44.6	42.4		38.7			4.[illegible]		[illegible]1.7	
	61.9	57.[illegible]		51.5			44.3						
		67		59.0									
11			72.9			59.9	56.9						
						68.0	64.1	60.8					
											56.7		
15										76.[illegible]			

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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 3.0

OFFSET FROM ZERO IN MICROVOLTS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+4[illegible]	+5[illegible]	+6[illegible]
	WATER POTENTIAL, NEGATIVE BARS												
1	5.5	[illegible]	[illegible]	4.7	[illegible]	4.4	4.2	4.0	[illegible]	3.7	3.6	[illegible]	[illegible]
[illegible]	11.1	[illegible]	[illegible]	9.6	9.2	[illegible]	8.4	8.1	[illegible]	7.5	7.3	7.0	6.8
3	17.0	[illegible]	[illegible]	14.6	13.9	13.3	12.8	12.3	[illegible]	11.4	11.0	10.6	10.3
4	23.0	[illegible]	[illegible]	19.7	[illegible]	18.0	17.3	16.6	[illegible]	15.3	14.8	14.3	13.8
5	29.2	[illegible]	[illegible]	25.0	23.8	22.8	21.8	20.9	[illegible]	19.4	18.7	18.0	17.4
[illegible]	35.7	33.8	32.0	30.4	29.0	[illegible]	26.5	25.4	24.4	23.5	22.7	21.9	21.1
[illegible]	[illegible]	40.2	38.1	36.1	[illegible]	[illegible]	31.4	30.1	28.9	27.8	26.7	25.8	24.9
[illegible]	50.0	47.0	[illegible]	42.1	40.0	[illegible]	36.4	34.9	33.4	32.1	30.9	29.8	28.8
9	58.1	54.4	51.2	48.4	45.9	[illegible]	41.7	39.9	38.2	36.7	35.3	34.0	32.7
[illegible]	67.5	62.6	58.6	55.2	52.2	[illegible]	47.2	45.1	43.1	41.4	39.7	38.2	36.8
11		72.6	[illegible]	62.7	59.1	55.9	53.1	[illegible]	48.3	46.3	44.4	42.7	41.1
12			[illegible]	71.7	66.8	62.8	59.4	[illegible]	53.8	51.4	[illegible]	47.3	45.5
1[illegible]					76.8	71.0	66.6	[illegible]	59.7	57.0	54.4	52.2	50.1
14							75.5	[illegible]	66.4	63.0	60.0	57.4	55.0
1[illegible]									74.4	69.9	66.2	63.0	60.3
1[illegible]										79.4	73.6	69.[illegible]	66.1
[illegible]												77.[illegible]	72.8
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- [illegible]
[illegible] CENTIGRADE --- 5.0

OFFSET FROM ZERO IN MICROVOLTS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	+10	+20	+30	+40	+50	+60
	WATER POTENTIAL, NEGATIVE BARS												
1	5.0	4.8	4.5	4.3	4.1	[illegible]	3.8	3.6	3.5	3.4	3.2	3.1	3.0
[illegible]	10.2	[illegible]	[illegible]	8.7	8.3	[illegible]	7.6	7.3	7.0	6.8	6.5	6.3	6.1
[illegible]	15.5	14.7	13.9	13.2	12.6	[illegible]	11.6	11.1	10.7	10.3	9.9	9.5	9.2
4	21.0	19.8	18.8	17.9	17.0	[illegible]	15.6	14.9	14.3	13.8	13.3	12.8	12.4
[illegible]	26.6	25.1	23.8	22.6	21.5	[illegible]	19.7	18.8	18.1	17.4	16.8	16.2	15.6
6	32.4	30.6	29.0	27.5	26.2	25.0	23.9	22.9	21.9	21.1	20.3	19.6	18.9
[illegible]	38.5	36.3	34.3	32.5	30.9	29.5	28.2	27.0	25.9	24.8	23.9	23.0	22.2
8	45.0	42.3	39.9	37.8	35.9	34.1	32.6	31.2	29.9	28.7	27.6	26.6	25.6
[illegible]	51.8	48.6	45.7	43.2	41.0	39.0	37.2	[illegible]	34.0	32.6	31.4	30.2	29.1
10	59.3	55.3	51.9	49.0	46.3	44.0	41.9	40.0	38.3	36.7	35.3	33.9	32.7
11	[illegible]	[illegible]	[illegible]	55.1	52.0	49.3	46.9	44.7	42.7	40.9	39.3	37.7	36.3
[illegible]	79.3	71.5	66.2	61.8	58.1	54.9	52.1	49.6	47.3	45.3	43.4	41.7	40.1
13			75.4	69.4	64.8	61.0	57.7	54.8	52.2	49.8	47.7	45.8	44.0
[illegible]				79.8	72.7	67.8	63.8	[illegible]	57.3	54.6	52.2	50.0	48.0
[illegible]						76.1	70.7	66.4	62.9	59.7	57.0	54.5	52.3
16							80.2	73.6	69.1	65.3	62.1	59.2	56.7
17									76.8	71.7	67.8	64.4	61.4
[illegible]										80.6	74.4	70.2	66.6
[illegible]												77.3	72.6
[illegible]													80.9

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PREDICTED WAI

COOLING TIME IN SECONDS
PSYCHROMETER TEMPERATURE, CENTIGRADE

OFFSET

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 7.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	4.7	4.4	4.2	4.0	3.8	3.6	3.5	3.3	3.2	3.1	3.0	2.9	2.8
2	9.4	8.9	8.4	8.0	7.6	7.3	7.0	6.7	6.4	6.2	6.0	5.8	5.6
3	14.3	13.5	12.8	12.1	11.6	11.0	10.6	10.1	9.7	9.3	9.0	8.7	8.4
4	19.3	18.2	17.2	16.4	15.6	14.9	14.2	13.6	13.1	12.6	12.1	11.7	11.2
5	24.4	23.0	21.8	20.7	19.7	18.7	17.9	17.2	16.5	15.8	15.2	14.7	14.2
6	29.7	28.0	26.4	25.1	23.8	22.7	21.7	20.8	19.9	19.1	18.4	17.7	17.1
7	35.2	33.1	31.3	29.6	28.1	26.8	25.6	24.5	23.4	22.5	21.6	20.8	20.1
8	40.9	38.4	36.2	34.3	32.5	30.9	29.5	28.2	27.0	25.9	24.9	24.0	23.1
9	46.9	44.0	41.4	39.1	37.1	35.2	33.6	32.1	30.7	29.5	28.3	27.2	26.2
10	53.3	49.8	46.8	44.1	41.8	39.7	37.8	36.0	34.5	33.1	31.7	30.5	29.4
11	60.1	56.0	52.4	49.4	46.7	44.2	42.1	40.1	38.4	36.7	35.3	33.9	32.6
12	67.9	62.8	58.5	54.9	51.8	49.0	46.6	44.4	42.4	40.5	38.9	37.3	35.9
13	77.5	70.4	65.2	60.9	57.2	54.1	51.3	48.8	46.5	44.5	42.6	40.9	39.3
14		81.0	72.9	67.5	63.1	59.4	56.2	53.3	50.8	48.5	46.4	44.5	42.8
15				75.4	69.7	65.3	61.5	58.2	55.3	52.7	50.4	48.3	46.4
16					77.9	71.9	67.3	63.4	60.1	57.2	54.6	52.2	50.1
17						80.8	74.0	69.2	65.3	61.9	59.0	56.3	54.0
18								76.1	71.1	67.1	63.7	60.7	58.0
19									78.2	72.9	68.8	65.3	62.3
20										80.7	74.7	70.5	66.9
M 21												76.6	72.1
22													78.5
I 23													
24													
C 25													
R 26													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ----------
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 8.0

	-60	-50	-4[illegible]		-20	-10								
1	4.[illegible]	4.3	4.0	3.8	[illegible]	[illegible].5				3.1	2.9	2.8		
2	[illegible]1	[illegible]	8.1	7.7	7.4	7.0	6.7	6.4			5.9	5.7		
3	13.8	[illegible]	12.3	11.7	11.1	10.6	10.1			[illegible]		[illegible]		
4	[illegible].6	[illegible]	[illegible]	[illegible]	14.9	14.3	13.6			[illegible]	[illegible]	[illegible]		10.8
5	[illegible]	22.1	[illegible]	[illegible]	18.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.1	14.6	14.0	13.5
6	28.[illegible]	26.9	25.4	24.0	22.8	21.8	[illegible]			19.1		[illegible]	17.0	16.4
7	[illegible].8	[illegible]	[illegible]	[illegible]	[illegible]	25.6	[illegible]	[illegible]	[illegible]	[illegible].4	[illegible]	[illegible]	[illegible]	
8	39.[illegible]	36.8	34.7	32.8	31.1	29.6	[illegible]			25.8	24.8	23.8	[illegible]	[illegible]
9	44.[illegible]	42.0	39.5	37.4	35.4	[illegible]	32.1	30.6	[illegible]	[illegible]	28.1	27.0	26.0	
10	[illegible].8	47.5	44.[illegible]	[illegible]	39.8	37.8	[illegible]	[illegible]	[illegible]	32.9	[illegible]		29.1	[illegible]
11	57.1	53.3	49.9	47.0	44.4	[illegible]	[illegible]			36.6	[illegible]			[illegible]
12	64.1	59.4	55.5	52.2	49.2	46.6	44.3	42.2	[illegible]	[illegible]	38.6	37.0	35.5	[illegible]
13	72.0	66.2	61.6	57.6	54.3	51.3	48.7	46.3	44.2	[illegible]	[illegible]	[illegible]	38.9	37.4
14		74.1	68.2	63.5	59.6	[illegible]	53.2	50.6	48.2	46.0	44.1	42.3	40.6
15			76.2	70.1	65.4	61.4	[illegible]		52.4	50.0	47.8	[illegible]	44.0
16				78.3	71.9	67.2	[illegible]		56.7	54.0	51.6	49.4	47.4
17					80.5	73.7	68.8	64.8	[illegible]	58.3	55.6		
18							[illegible]	[illegible]	66.3	[illegible]	[illegible]	57.1	[illegible]
19								77.1	71.9	[illegible]	[illegible]	61.3	58.6
20									78.8	[illegible]	[illegible]	65.7	62.6
21											80.6	74.8	70.6	67.0
22													76.2	71.9
23														77.6
24														
25														
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M I C R O V L T R E A D I N G

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 9.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10		+10	+20	+30	+40	+50	+60
1	4.3	4.1	3.9	3.7	3.5	3.4	3.2	3.1	3.0	2.8	2.7	2.6	2.5
2	[illegible]	8.3	[illegible]	7.4	7.1	6.8	6.5	6.2	5.9	5.7	5.5	5.3	5.1
3	[illegible]	12.5	11.9	11.3	10.7	10.2	9.8	9.3	9.0	8.6	8.3	8.0	7.7
4	[illegible]	16.9	16.0	15.1	14.4	13.7	13.1	12.5	12.0	11.6	11.1	10.7	10.3
5	[illegible]	21.3	20.1	19.1	18.1	17.3	16.5	15.8	15.1	14.5	14.0	13.5	13.0
6	27.5	25.9	24.4	23.1	22.0	20.9	20.0	19.1	18.3	17.6	16.9	16.3	15.7
7	[illegible]	30.5	28.8	27.2	25.9	24.6	23.5	22.4	21.5	20.6	19.8	19.1	18.4
8	37.6	35.3	33.3	31.5	29.8	28.4	27.1	25.9	24.8	23.8	22.8	22.0	21.2
9	43.[illegible]	40.3	37.9	35.8	33.9	32.3	30.7	29.3	28.1	26.9	25.9	24.9	24.0
10	48.[illegible]	45.4	42.7	40.3	38.1	36.2	34.5	32.9	31.5	30.2	29.0	27.8	26.8
11	54.[illegible]	50.8	47.7	44.9	42.5	40.3	38.3	36.6	34.9	33.5	32.1	30.9	29.7
12	[illegible]	56.6	52.9	49.7	47.0	44.5	42.3	40.3	38.5	36.8	35.3	33.9	32.7
13	67.8	62.7	58.5	54.8	51.6	48.9	46.4	44.1	42.1	40.3	38.6	37.1	35.7
14	75.2	69.5	64.4	60.2	56.6	53.4	50.6	48.1	45.9	43.8	42.0	40.3	38.7
15		77.9	71.1	66.0	61.8	58.2	55.0	52.3	49.8	47.5	45.5	43.6	41.9
16			79.5	72.6	67.5	63.3	59.7	56.6	53.8	51.3	49.0	47.0	45.1
17				81.3	74.0	68.9	64.7	61.1	58.0	55.2	52.7	50.5	48.4
18						75.4	70.2	66.0	62.5	59.4	56.6	54.1	51.8
19							76.6	71.5	67.3	63.7	60.6	57.9	55.4
20								77.9	72.6	68.5	64.9	61.8	59.1
M 21									79.1	73.8	69.6	66.1	63.0
22										80.4	74.9	70.7	67.1
I 23											81.8	75.9	71.7
24													76.9
C 25													
R 26													
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COOLING TIME IN SE[illegible]

[illegible]	[illegible]	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8.5	8.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	17.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	26.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	31.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	36.2	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	[illegible]
[illegible]	41.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	46.6	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	48.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	58.1	54.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	59.7	[illegible]	52	49.4	[illegible]	[illegible]	[illegible]
14	71.6	65.9	61.2	57	[illegible]	[illegible]	41.9	[illegible]
15	80.6	[illegible]	[illegible]	[illegible]	[illegible]	49.8	47.9	[illegible]
[illegible]	[illegible]	81.9	73	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	83	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70.	62.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.3	74.
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 11.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	4.1	3.9	3.6	3.5	3.3	3.1	3.0	2.9	2.7	2.6	2.5	2.4	2.4
2	9.2	7.8	7.3	7.0	6.6	6.3	6.0	5.8	5.5	5.3	5.1	4.9	4.7
3	12.9	11.7	11.1	10.5	10.0	9.5	9.1	8.7	8.3	8.0	7.7	7.4	7.2
4	16.8	15.8	14.9	14.1	13.4	12.8	12.2	11.7	11.2	10.7	10.3	9.9	9.6
5	21.2	19.9	18.8	17.8	16.9	16.1	15.3	14.7	14.1	13.5	13.0	12.5	12.0
6	25.7	24.1	22.7	21.5	20.4	19.4	18.5	17.7	17.0	16.3	15.6	15.1	14.5
7	30.3	28.4	26.8	25.3	24.0	22.8	21.8	20.8	19.9	19.1	18.4	17.7	17.0
8	35.0	32.8	30.9	29.2	27.7	26.3	25.1	23.9	22.9	22.0	21.1	20.3	19.6
9	39.8	37.3	35.1	33.2	31.4	29.8	28.4	27.1	26.0	24.9	23.9	23.0	22.1
10	44.9	42.0	39.5	37.2	35.2	33.4	31.8	30.4	29.1	27.8	26.7	25.7	24.7
11	50.1	46.8	43.9	41.4	39.1	37.1	35.3	33.7	32.2	30.8	29.6	28.4	27.4
12	55.6	51.8	48.6	45.7	43.2	40.9	38.9	37.1	35.4	33.9	32.5	31.2	30.0
13	61.5	57.1	53.4	50.2	47.3	44.8	42.5	40.5	38.7	37.0	35.5	34.1	32.8
14	67.9	62.8	58.5	54.8	51.6	48.8	46.3	44.0	42.0	40.2	38.5	36.9	35.5
15	75.2	68.9	63.9	59.7	56.1	53.0	50.2	47.7	45.5	43.4	41.6	39.9	38.3
16		75.9	69.8	64.9	60.8	57.3	54.2	51.4	49.0	46.8	44.7	42.9	41.2
17			76.6	70.6	65.8	61.8	58.4	55.3	52.6	50.2	48.0	46.0	44.1
18				77.2	71.4	66.7	62.8	59.4	56.4	53.7	51.3	49.1	47.1
19					77.8	72.0	67.5	63.7	60.3	57.4	54.7	52.4	50.2
20						78.3	72.7	68.3	64.5	61.2	58.3	55.7	53.3
M 21							78.8	73.3	68.9	65.3	62.0	59.2	56.6
22								79.3	73.9	69.6	66.0	62.8	60.0
I 23									79.7	74.4	70.2	66.6	63.5
24										80.1	74.9	70.8	67.3
C 25											80.5	75.3	71.3
R 26												80.9	75.8
27													81.3
O 28													
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PSYCHROMETER TEMPERATURE, CENTIGRADE --- 12.0

	-60	-50	-40			-10							
					WATER								
1				.4			2.9						
2	8.					6.1							
3	12.1	11.4	10.8		9.7			.4			7		
4		15.3				12.4							
5					16.4				13.6				
6				20.8			17.9						14.0
7		27.5				22.1		20.1	19.		17.1		
8	8	31.7	29.9		26.7				21.1	.4			
9		36.1			30.3		27.4						
10	4.		36.1					29.3	26.0				
11	48.	4			37.7								
12	5	49.9		44.0	41.6		37.4	35.7					
13	59	54.8	51.3		45.5								
14	4.	60.1	56.0	52.6	49.5	46.9	44.5		40.4				
15		65.7		57.1	53.8	50.8				41.7			
16	9	71.8				54.8					41		
17		79.1		67.1						48.1	44.1		
18				72.7		63.5		56.7		51.4	49.1	47	
19				79.4	73.1			60.7		54.6		1	
20						73.5				58.4	55.7		
M 21						79.6						4	54.0
22							79.7	74.1					
I 23								79.8	74.4				
24										74.6			
25										80.0			
R 26											80.0		71.1
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PREDICTED WATER POTENTIAL

[illegible] TIME IN [illegible] ---------------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 13.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	[illegible]	+10	+20	+30	+40	+50	+60
1	[illegible]	[illegible]	3.4	3.3	3.1	3.0	2.8	2.7	2.6	2.5	2.4	2.3	2.2
2	[illegible]	7.3	6.9	[illegible]	6.2	5.9	5.7	5.4	5.2	5.0	4.8	4.6	4.4
3	[illegible]	11.1	10.5	9.9	9.4	8.9	8.5	8.2	7.8	7.5	7.2	6.9	6.7
4	[illegible]	14.9	14.0	13.3	12.6	12.0	11.4	10.9	10.5	10.0	9.7	9.3	9.0
5	[illegible]	18.7	17.7	16.7	15.9	15.1	14.4	13.7	13.2	12.6	12.1	11.7	11.2
6	[illegible]	22.7	21.4	20.2	19.2	18.2	17.4	16.6	15.9	15.2	14.6	14.1	13.6
7	[illegible]	26.7	25.1	23.7	22.5	21.4	20.4	19.5	18.6	17.8	17.1	16.5	15.9
8	[illegible]	30.8	28.9	27.3	25.9	24.6	23.4	22.4	21.4	20.5	19.7	18.9	18.2
9	37.3	34.9	32.8	31.0	29.3	27.9	26.5	25.3	24.2	23.2	22.3	21.4	20.6
10	41.9	39.2	36.8	34.7	32.9	31.2	29.7	28.3	27.1	25.9	24.9	23.9	23.0
11	46.7	43.6	40.9	38.5	36.4	[illegible]	32.9	31.3	29.9	28.7	27.5	26.4	25.4
12	51.6	48.1	45.1	42.4	40.1	38.0	36.1	34.4	32.9	31.5	30.2	29.0	27.9
13	56.3	52.8	49.4	46.5	43.8	41.5	39.4	37.6	35.9	34.3	32.9	31.6	30.4
14	[illegible]	57.7	53.9	50.6	47.7	45.1	42.8	40.8	38.9	37.2	35.6	34.2	32.9
15	[illegible]	62.9	58.6	54.9	51.7	48.8	46.3	44.0	42.0	40.1	38.4	36.9	35.5
16	74.6	68.5	63.5	[illegible]	55.8	52.6	49.9	47.4	45.2	43.1	41.3	39.6	38.1
17	[illegible]	74.6	68.8	64.1	60.1	56.6	53.5	50.8	48.4	46.2	44.2	42.4	40.7
18		82.4	74.7	69.1	64.6	60.7	57.3	54.4	51.7	49.3	47.2	45.2	43.4
19			81.9	74.7	69.4	65.0	61.3	58.0	55.1	52.5	50.2	48.1	46.1
20				81.5	74.7	69.7	65.5	61.8	58.7	55.8	53.3	51.0	48.9
M 21					81.1	74.8	69.9	65.9	62.3	59.3	56.5	54.0	51.7
22						80.8	74.8	70.1	66.2	62.8	59.8	57.1	54.7
I 23							80.5	74.8	70.3	66.5	63.2	60.3	57.7
24								80.3	74.8	70.5	66.9	63.6	60.8
C 25									80.0	74.8	70.7	67.1	64.0
R 26										79.8	74.8	70.8	67.4
27											79.6	74.9	71.0
O 28												79.4	74.9
29													79.3

PREDICTED WATER POTENTIAL

TIME IN SECONDS -- [illegible] 60.0
[illegible] CENTIGRADE --- 15.0

OFFSET FROM ZERO IN MICROVOLTS

				-30	-20	-10		+10	+20	+30	[illegible]	[illegible]	+60
				POTENTIAL, NEGATIVE [illegible]									
				[illegible]	2.9		2.7	2.5	2.4	2.3	2.2	2.2	2.1
				[illegible]	[illegible]	[illegible]	[illegible]	5.1	4.9	4.7	4.5	4.3	4.2
11				[illegible]	[illegible]	[illegible]	[illegible]	7.7	7.4	7.1	[illegible]	6.5	6.3
	1	13.3	[illegible]		11.9	11.3	10.8	10.3	9.9	9.5	9.1	8.7	8.4
18	[illegible]	16.7	15.8		15.0	14.2	13.6	13.0	12.4	11.9	11.4	11.0	[illegible]
			19.1		18.1	17.2	16.4	15.6	14.9	14.3	13.7	13.2	12.7
7	26	23.7	22.4		21.2	20.1	[illegible]	18.3	17.5	[illegible]	16.1	15.5	14.9
	0		25.8		[illegible]	23.1	22.0	21.0	20.1	19.3	18.5	17.8	17.1
	[illegible]	[illegible]	29.2		27.6	[illegible]	[illegible]	23.8	22.7	21.8	[illegible]	20.1	19.3
[illegible]	[illegible]	[illegible]	32.6		30.9	29.3	27.8	26.5	25.4	24.3	23.3	22.4	21.5
11	48	[illegible]	36.2		[illegible]	[illegible]	[illegible]	[illegible]	28.0	26.8	25.7	24.7	23.8
12	[illegible]	1	42.2	39.8	37.6	[illegible]	[illegible]	32.2		29.4	28.2	27.1	26.1
[illegible]	58.0	49.3	[illegible]	[illegible]	41.0	38.8	[illegible]	[illegible]	33.5	32.1	30.7	[illegible]	[illegible]
[illegible]	[illegible]	.7	[illegible]	47.2	44.5	42.1	[illegible]	[illegible]	36.3	34.7	[illegible]	31.9	30.7
[illegible]	[illegible]	.3	54.4	51.0	48.1	45.5	43.1	41.0	39.1	37.4	35.8	34.4	33.0
[illegible]	[illegible]	1	[illegible]	55.0	51.8	[illegible]	46.4	44.1	42.0	40.1	38.4	36.9	35.4
17	[illegible]	.2	63.3	59.2	55.6	[illegible]	49.7	47.2	45.0	42.9	41.1	39.4	37.8
[illegible]	[illegible]	.7	68.1	63.5	59.5	56.1	53.1	50.4	47.9	45.8	43.8	41.9	40.3
[illegible]		.1	[illegible]	68.0	63.6	59.8	56.5	53.6	51.0	48.6	46.5	44.[illegible]	42.8
20			[illegible]	72.9	67.9	63.7	60.1	56.9	54.1	51.6	49.3	47.2	[illegible]
[illegible]				78.4	72.5	67.8	63.9	60.4	57.3	54.6	52.1	49.9	47.8
[illegible]					77.7	72.2	67.8	[illegible]	60.6	57.7	[illegible]	52.6	50.4
					84.3	77.1	[illegible]	67.7	64.1	[illegible]	58.0	[illegible]	53.1
[illegible]						82.9	[illegible]	71.7	67.7	64.2	61.1	58.3	55.8
[illegible]							[illegible]	76.0	71.5	67.6	64.3	61.3	58.6
[illegible]								[illegible]	75.6	71.2	[illegible]	64.3	61.5
27									80.2	75.2	71.1	67.5	64.4
[illegible]										[illegible]	74.8	70.9	[illegible]
29											78.9	74.4	70.7
											[illegible]	78.4	74.1
0												[illegible]	77.9
													82.2
[illegible] 40													
14													
49													
52													
56													
64													
69													

PREDICTED WATER POTENTIAL

[illegible] ---------------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 17.0

OFFSET FROM ZERO IN MICROVOLTS

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+4	[illegible]	[illegible]
	WATER POTENTIAL, NEGATIVE BARS												
	3.5	[illegible]	.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].4	[illegible]	2.2	[illegible]	2.0	2.0
	7.1	6.7	[illegible]	5.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.4	[illegible]	4.1	4.0
	10.7	10.[illegible]	[illegible]	8.9	8.4	[illegible]	[illegible]	[illegible]	[illegible]	6.7	[illegible]	6.2	5.9
	[illegible]	13.4	[illegible]	11.9	11.3	[illegible]	[illegible]	[illegible]	[illegible]	8.9	[illegible]	[illegible]	7.9
	18.0	16.9	[illegible]	15.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.2	[illegible]	10.4	10.0
	[illegible]	[illegible]	.2	[illegible]	17.1	16.[illegible]	[illegible].5	[illegible].8	14.1	13.[illegible]	[illegible]	[illegible]	12.0
7	.6	.9	22[illegible]	[illegible]	[illegible]	19.1	[illegible].1	[illegible].3	16.5	[illegible]	15.2	14.6	14.[illegible]
	29.4	27[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].8	19.8	[illegible]	18.2	[illegible]	16.7	[illegible].1
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].1	[illegible]	[illegible].5	[illegible].4	[illegible].4	[illegible].5	[illegible].7	[illegible]	[illegible]
10	[illegible].4	[illegible]	.7	30[illegible]	29.1	[illegible].6	[illegible]	25.0	[illegible].9	[illegible].9	[illegible]	[illegible].1	[illegible].3
11	[illegible].4	[illegible]	.2	[illegible].1	32.[illegible]	[illegible].5	[illegible]	[illegible]	26.4	[illegible]	[illegible]	[illegible]	22.4
12	45.6	[illegible]	[illegible].8	[illegible].5	35.4	33.[illegible]	31.8	[illegible].3	[illegible].9	[illegible].7	[illegible]	[illegible].5	[illegible]
	[illegible].9	46.[illegible]	[illegible]	40.9	38.[illegible]	36.[illegible]	34.7	[illegible].0	31.[illegible]	[illegible].1	28.9	27.7	26.6
	[illegible]	[illegible]	47.2	44.3	41.[illegible]	[illegible]	37.5	[illegible].7	[illegible].1	[illegible].6	[illegible].2	[illegible]	[illegible]
	[illegible]	[illegible].6	[illegible].0	47.9	45.1	42.6	[illegible].5	[illegible].5	[illegible].7	[illegible].1	33.[illegible]	32.2	[illegible].0
	[illegible].6	[illegible].9	[illegible].9	51.5	[illegible].5	[illegible].8	43.4	41.3	[illegible].3	[illegible].6	36.0	34.5	33.2
17	[illegible].6	63.4	[illegible].0	55.2	[illegible].9	[illegible].0	[illegible].4	44.1	42.0	40.1	[illegible].4	[illegible].8	[illegible].4
	74[illegible]	68.[illegible]	[illegible]	[illegible].0	[illegible]	52.3	[illegible].5	[illegible].0	[illegible].8	[illegible].7	[illegible].9	[illegible]	[illegible].6
		.1	67.[illegible]	[illegible].0	59.1	[illegible].7	[illegible].6	[illegible].0	47.[illegible]	[illegible].4	43.[illegible]	41.6	[illegible].9
		78.6	[illegible].2	[illegible].1	62.[illegible]	[illegible].1	[illegible].9	53.0	[illegible].4	[illegible].0	45.[illegible]	44.[illegible]	42.[illegible]
			77[illegible]	[illegible]	[illegible].7	[illegible]7	[illegible].1	56.0	53.[illegible]	[illegible].8	48.5	[illegible].4	44.5
22			[illegible].5	[illegible]	70.9	[illegible]	[illegible]	59.2	[illegible].2	[illegible]	51.1	[illegible].9	[illegible]
				[illegible]	75.[illegible]	[illegible]	[illegible]	[illegible].4	[illegible].2	[illegible].4	53.[illegible]	51.4	49.[illegible]
					[illegible].2	[illegible].4	69.8	[illegible]	[illegible]	[illegible]	[illegible].5	54.0	[illegible]1.7
						[illegible].0	73.7	[illegible]	[illegible].5	[illegible].2	[illegible]	[illegible].6	[illegible]
						4[illegible]	[illegible].9	73.[illegible]	[illegible].9	[illegible].3	[illegible].1	[illegible].3	[illegible].7
							82.[illegible]	[illegible].0	[illegible].4	[illegible]	[illegible].1	62.1	59.3
								[illegible].5	[illegible].1	71.8	[illegible].1	[illegible]	62.0
29									[illegible]	75.[illegible]	71.3	[illegible].8	64.7
										[illegible].2	[illegible].7	70.8	67.5
										[illegible].9	[illegible].3	74.1	70.4
32											82.5	[illegible].5	73.5
33												[illegible].3	76.[illegible]
													[illegible].3
													84.8

PREDICTED WATER POTENTIAL

[illegible] 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 19.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	3.4	3.2	3.0	[illegible]	2.7	2.5	2.4	2.3	2.2	[illegible]	2.0	1.9	1.9
	[illegible]	6.4	6.0	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0	3.9	3.7
	10.2	9.6	9.0	8.5	8.0	7.6	7.3	[illegible]	6.6	6.3	6.1	5.8	5.6
	13.7	12.8	12.1	11.4	10.8	10.2	9.7	9.3	[illegible]	8.5	8.1	7.8	7.5
	17.2	16.1	15.1	14.3	13[illegible]	[illegible]	12.2	11.6	11.1	10.6	10.2	9.8	9.4
	[illegible]	19.4	18.[illegible]	17.[illegible]	[illegible]3	15.4	14.7	14.0	13.4	[illegible]	12.3	11.8	11.3
7	[illegible]	[illegible]8	21.[illegible]	[illegible].2	[illegible].1	[illegible].1	17.2	16.4	15.6	15.0	14.4	[illegible]	13.3
	[illegible]	[illegible]	[illegible].6	[illegible]	[illegible]	[illegible].7	19.7	18.8	17.9	17.2	16.5	15.8	[illegible]
	[illegible].7	[illegible].6	[illegible]	[illegible]	[illegible].7	[illegible].4	22.3	21.2	20.2	[illegible]	18.6	17.8	17.1
10	[illegible].5	[illegible]	[illegible]	[illegible].2	27.[illegible]	[illegible].1	24.8	23.6	22.6	21.6	20.7	19.9	19.1
11	[illegible].3	[illegible].7	[illegible]	32.[illegible]	[illegible].5	28.[illegible]	27.4	26.1	24.9	23.8	22.8	21.9	21.1
12	43	40.[illegible]	[illegible]	[illegible].4	[illegible]4	31.7	30.1	28.6	27.3	26.1	25.0	24.0	23.1
[illegible]	[illegible].2	4[illegible].9	[illegible].1	[illegible]	[illegible].4	[illegible].5	32.7	31.1	29.7	28.4	27.2	26.1	25.1
[illegible]	[illegible]	47.7	44.5	41.8	[illegible].4	[illegible]	35.4	33.7	32.1	30.7	29.4	28.2	27.1
[illegible]	55.4	[illegible].5	48.1	45.1	[illegible].5	40.[illegible]	[illegible]	[illegible]	34.5	33.0	31.6	30.3	29.1
1[illegible]	59.7	[illegible].4	[illegible]	46.4	45.[illegible]	[illegible].1	[illegible]	[illegible]	37.0	35.3	[illegible]	32.4	31.2
[illegible]	[illegible].2	[illegible].4	[illegible]	[illegible].8	48.[illegible]	[illegible].1	[illegible]	41.5	39.5	37.7	36.1	34.6	33.2
[illegible]	[illegible].9	[illegible].6	[illegible].1	[illegible].3	[illegible].0	49.1	46.5	44.1	42.0	40.1	38.4	36.8	35.3
19	73.9	67.[illegible]	[illegible].0	[illegible]	[illegible].3	[illegible].1	49.3	46.8	44.6	42.5	40.7	39.0	37.4
20	[illegible].4	72.[illegible]	67.1	62.6	[illegible].7	[illegible]	52.3	49.6	47.2	45.0	43.0	41.2	39.5
[illegible] 21	[illegible]	77.5	[illegible].4	[illegible].4	[illegible]	[illegible]	55.2	52.4	49.8	47.5	45.4	43.5	41.7
[illegible]	[illegible]	83.4	[illegible]	70.4	65.[illegible]	61.8	58.3	55.2	52.5	50.0	47.8	45.7	43.9
I [illegible]	[illegible]	[illegible]	1.1	[illegible]	69.[illegible]	[illegible].1	61.4	58.1	55.2	52.6	50.2	48.0	46.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible].2	[illegible].4	[illegible]	64.6	61.1	58.0	55.2	52.7	[illegible].4	[illegible]
C [illegible]	[illegible]	[illegible]	[illegible]	[illegible]4.8	77.[illegible]	72.4	[illegible]	64.2	60.8	57.8	55.2	52.7	50.5
[illegible] 26	[illegible]	[illegible]	[illegible]	[illegible].5	[illegible].3	[illegible]	71.4	67.3	63.7	60.6	[illegible]	[illegible]	52.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].6	[illegible]	75.1	70.6	66.7	[illegible]	60.3	57.6	55.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.1	74.0	69.8	66.2	63.0	60.1	57.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83.7	77.7	73.1	69.2	65.7	62.6	59.9
V 30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	76.5	72.2	68.5	65.3	62.3
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.3	75.5	71.5	68.0	64.9
3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	78.9	74.5	70.7	67.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	82.9	77.8	73.6	70.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.3	76.7	72.9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85.9	[illegible]	75.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	78.9
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I 45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] 46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PREDICTED WATER POTENTIAL

[illegible]

PSYCHROMETER TEMPERATURE, CENTIGRADE --- 21.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	[illegible]	-40	[illegible]	[illegible]	[illegible]	[illegible]	+10	+20	[illegible]	+40	+50	[illegible]
1	3.2	3.0	2.8	2.7	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.8
	6.5	6.1	5.7	5.4	5.1	4.8	4.6	4.4	4.2	4.0	3.8	3.7	3.5
3	9.8	9.2	8.6	8.1	7.7	7.3	6.9	6.6	6.3	6.0	5.8	5.5	5.3
4	13.1	12.3	11.5	10.8	10.2	9.7	9.2	8.8	8.4	8.0	7.7	7.4	7.1
5	16.5	15.4	14.4	13.6	12.8	12.2	11.6	11.0	10.5	10.1	9.7	9.3	8.9
6	[illegible]	[illegible]	[illegible]	16.4	15.5	14.7	13.9	13.3	12.7	12.1	11.6	11.1	10.7
[illegible]	[illegible]	21.7	[illegible]	[illegible]	18.1	17.2	16.3	15.5	14.8	14.2	13.6	[illegible]	12.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.8	19.7	18.7	17.8	17.0	16.2	15.6	14.9	14.4
[illegible]	[illegible]	[illegible]	[illegible]	24.9	23.5	22.2	21.1	20.1	19.2	18.3	17.6	16.9	16.2
[illegible]	[illegible]	31.5	[illegible]	[illegible]	26.2	24.8	23.5	22.4	21.4	20.4	19.6	18.8	18.0
11	[illegible]	[illegible]	32.6	[illegible]	[illegible]	27.4	26.0	24.7	23.6	22.5	21.6	20.7	19.9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31.7	30.0	28.4	27.1	25.8	24.7	23.6	22.7	21.8
13	[illegible]	[illegible]	[illegible]	[illegible]	34.5	32.6	30.9	29.4	28.0	26.8	25.7	24.6	23.6
14	[illegible]	[illegible]	42.2	[illegible]	37.3	35.3	33.4	31.8	30.3	29.0	27.7	26.6	25.5
[illegible]	[illegible]	48.7	[illegible]	[illegible]	40.2	38.0	[illegible]	34.2	32.6	31.1	29.8	28.6	27.4
[illegible]	[illegible]	[illegible]	[illegible]	45.7	43.1	[illegible]	38.5	[illegible]	34.9	[illegible]	31.9	30.6	29.4
[illegible]	[illegible]	56.0	[illegible]	[illegible]	46.0	43.4	41.1	[illegible]	37.2	35.5	[illegible]	32.6	31.3
[illegible]	64.7	[illegible]	[illegible]	[illegible]	[illegible]	46.2	43.8	41.6	39.6	37.8	36.1	34.6	33.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49.1	46.4	44.1	41.9	40.0	[illegible]	36.7	35.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55.1	51.9	49.1	46.6	[illegible]	42.3	40.4	38.7	37.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58.3	54.9	51.9	49.2	46.8	44.6	42.6	40.8	39.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.5	57.8	54.6	51.8	49.2	46.9	44.8	42.9	41.2
[illegible]		[illegible]	74.8	[illegible]	64.8	60.9	57.5	54.4	51.7	49.3	47.1	45.0	43.2
[illegible]			79.3	[illegible]	68.2	64.0	60.4	57.1	54.3	[illegible]	[illegible]	47.2	45.2
[illegible]			[illegible]	[illegible]	71.8	67.3	63.3	[illegible]	[illegible]	54.1	51.6	49.4	47.3
[illegible]				[illegible]	75.6	70.6	66.4	62.7	59.4	56.5	53.9	51.6	49.4
27					79.7	[illegible]	69.5	65.6	62.1	59.0	56.3	53.8	51.5
[illegible]					84.4	77.8	[illegible]	68.5	64.9	61.6	58.7	56.1	53.7
[illegible]						81.9	76.2	71.6	67.7	64.2	61.1	58.3	55.8
[illegible]							79.9	74.8	70.6	66.9	63.6	60.7	58.0
[illegible]							[illegible]	78.3	73.6	69.6	66.2	63.1	60.3
[illegible]								82.0	[illegible]	72.5	68.8	65.5	62.6
[illegible]									80.2	75.5	71.5	68.0	64.9
[illegible]									84.1	78.6	74.3	70.6	67.3
[illegible]										82.1	77.2	73.2	69.7
[illegible]											80.4	76.0	72.2
[illegible]											84.0	78.9	74.9
[illegible]												82.1	77.6
[illegible]												86.1	[illegible]
40													[illegible]

PSYCHROMETER TEMPERATURE, CEN

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 23.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	[illegible]	[illegible]	2.7	[illegible]	2.4	[illegible]	[illegible]	2.1	2.0	1.9	1.8	1.7	1.7
	[illegible]	[illegible]	[illegible]	5.4	5.1	4.8	4.8	4.4	4.2	4.0	3.8	3.6	3.5	3.4
	[illegible]	[illegible]	[illegible]	8.2	7.7	7.3	[illegible]	[illegible]	6.2	6.0	5.7	5.5	5.2	5.0
	4	[illegible]	11.7	11.0	10.3	9.7	9.2	8.8	8.3	8.0	7.6	7.3	7.0	6.7
	[illegible]	[illegible]	14.7	13.8	12.9	12.2	11.6	11.0	10.5	10.0	9.5	9.1	8.8	8.4
	[illegible]	[illegible]	17.7	16.6	15.6	14.7	13.9	13.2	12.6	12.0	11.5	11.0	10.6	10.1
	7	22.2	20.7	19.4	18.[illegible]	17.2	16.3	15.5	14.7	14.0	13.4	12.9	12.3	11.9
	[illegible]	[illegible]	23.8	22.3	[illegible]	19.7	18.7	17.7	16.9	16.1	15.4	14.7	14.1	13.6
	9	[illegible]	26.9	25.2	[illegible]	22.3	21.1	20.0	19.0	18.2	17.4	16.6	15.9	15.3
	10	[illegible]	30.0	28.1	[illegible]	24.9	23.5	22.3	21.2	20.2	19.3	18.5	17.8	17.1
	11	[illegible]	[illegible]	31.[illegible]	29.1	27.4	26.0	24.6	[illegible]	22.3	21.3	20.4	19.6	18.8
	12	[illegible]	36.4	[illegible]	[illegible]	30.0	28.4	26.9	25.6	24.4	23.3	22.3	21.4	20.6
	1[illegible]	42.[illegible]	[illegible]	37.0	34.7	32.7	[illegible]	29.3	27.8	26.5	25.3	24.3	23.3	22.3
	14	46.[illegible]	[illegible]	[illegible]	[illegible]	35.3	33.4	31.6	30.1	28.7	27.4	26.2	25.1	24.1
	15	[illegible]	[illegible]	[illegible]	40.4	38.0	35.9	34.0	32.3	[illegible]	29.4	28.1	27.0	25.9
	16	53.5	[illegible]	[illegible]	[illegible]	40.7	38.5	36.4	[illegible]	33.0	31.5	30.1	[illegible]	27.7
	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.0	[illegible]	36.9	35.1	33.5	32.1	30.7	29.5
	18	61.1	[illegible]	[illegible]	49.2	46.3	43.6	41.3	39.2	37.3	35.6	34.1	32.6	31.3
	19	65.1	[illegible]	[illegible]	[illegible]	49.1	[illegible]	43.8	41.6	39.6	37.7	36.1	34.6	33.2
	20	[illegible]	[illegible]	59.3	[illegible]	51.9	[illegible]	46.3	43.9	41.8	39.9	38.1	36.5	35.0
M	21	[illegible]	[illegible]	62.7	[illegible]	54.9	51.7	48.8	46.3	44.0	42.0	40.1	38.4	36.9
	22	78.3	71.6	66.3	[illegible]	57.8	54.4	51.4	48.7	46.3	44.2	42.2	40.4	38.7
I	23	[illegible]	[illegible]	[illegible]	[illegible]	60.8	57.2	54.0	51.2	48.6	46.3	44.3	42.4	40.6
	24		[illegible]	73.8	[illegible]	63.9	60.1	56.7	53.7	51.0	48.5	46.4	44.4	42.5
C	25		[illegible]	77.8	[illegible]	67.1	[illegible]	59.4	56.2	53.3	50.8	48.5	46.4	44.4
R	26			82.3	[illegible]	70.4	66.0	62.1	58.7	[illegible]	53.0	50.6	48.4	46.4
	27				79.7	73.8	69.0	64.9	61.4	58.2	55.3	52.8	50.4	48.3
O	28				84.2	77.4	72.2	67.8	64.0	[illegible]	57.7	55.0	52.5	50.3
	29					81.4	75.6	70.8	66.7	63.2	60.0	57.2	54.6	52.3
V						86.1	79.1	73.9	[illegible]	[illegible]	62.4	59.4	56.8	54.3
O	31						[illegible]	77.1	72.4	68.4	64.9	61.7	[illegible]	56.4
	32							80.6	75.4	71.1	67.4	64.1	61.1	58.4
L	33							84.6	78.6	[illegible]	70.0	66.5	63.3	60.5
	34								82.1	76.9	72.6	68.9	65.6	62.7
T	35								86.3	80.0	75.4	71.4	67.9	64.8
	36									83.5	78.3	74.0	70.3	67.0
	37										81.4	76.7	72.8	69.3
R	38										84.9	79.5	75.3	71.6
	39											82.6	77.9	74.0
E	40											86.4	[illegible]	76.5
A	41												83.9	79.1
	42													81.9
D	43													85.2
	44													
I	45													
N	46													
	47													
	48													
	49													
	[illegible]													
	51													
	52													
	[illegible]													
	54													
	[illegible]													
	[illegible]													
	[illegible]													
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	[illegible]													
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	[illegible]													
	62													
	[illegible]													
	[illegible]													
	66													

COOLING TIME IN SECONDS -
PSYCHROMETER TEMP[illegible] CENTIGRADE

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 25.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	[illegible]	[illegible]	[illegible]	2.4	2.3	[illegible]	[illegible]	[illegible]	1.9	1.8	1.7	1.7	1.6
	2	[illegible]	5.6	5.2	4.9	4.6	4.4	4.1	3.9	3.8	3.6	3.4	3.3	3.2
	3	9.0	8.4	7.8	7.4	6.9	6.6	6.2	5.9	5.7	5.4	5.2	5.0	4.8
	4	[illegible]	11.2	10.5	9.8	9.3	8.8	8.3	7.9	7.6	7.2	6.9	6.6	6.4
	5	[illegible]	14.0	13.1	12.3	11.6	11.0	10.4	9.9	9.5	9.1	8.7	8.3	8.0
	6	[illegible]	16.9	15.8	14.8	14.0	13.2	12.6	12.0	11.4	10.9	10.4	10.0	9.6
	7	[illegible]	19.8	18.5	17.4	16.4	15.5	14.7	14.0	13.3	12.7	12.2	11.7	11.2
	8	24.4	22.7	21.2	19.9	18.8	17.8	16.8	16.0	15.3	14.6	14.0	13.4	12.9
	9	27.5	25.6	23.9	22.5	21.2	20.0	19.0	18.1	17.2	16.4	15.7	15.1	14.5
	10	[illegible]	28.6	26.7	25.1	23.6	22.3	21.2	20.1	19.2	18.3	17.5	16.8	16.1
	11	34.0	31.6	29.5	27.7	26.1	24.6	23.3	22.2	21.1	20.2	19.3	18.5	17.8
	12	37.[illegible]	34.6	32.3	30.3	28.5	27.0	25.5	24.3	23.1	22.1	21.1	20.3	19.5
	13	40.5	37.6	35.1	[illegible]	31.0	29.3	27.8	26.4	25.1	24.0	23.0	22.0	21.1
	14	[illegible]	40.7	38.0	35.6	33.5	31.7	30.0	28.5	27.1	25.9	24.8	23.7	22.8
	15	47.3	43.9	40.9	38.3	36.0	34.0	32.2	30.6	29.2	27.8	26.6	25.5	24.5
	16	[illegible]	47.0	43.8	41.0	38.6	36.4	34.5	32.8	31.2	29.8	28.5	27.3	26.2
	17	54.3	50.3	46.8	43.8	41.2	38.8	36.8	34.9	33.2	31.7	30.3	29.0	27.9
	18	57.9	53.5	49.8	46.6	43.8	41.3	39.1	37.1	35.3	33.7	32.2	30.8	29.6
	19	61.6	56.9	52.9	49.4	[illegible]	43.8	41.4	39.3	37.4	35.6	34.1	32.6	31.3
	20	[illegible]	60.3	56.0	52.3	49.1	46.3	43.7	41.5	39.5	37.6	36.0	34.4	33.0
M	21	69.3	61.[illegible]	59.2	55.2	51.8	48.8	46.1	43.7	41.6	39.6	37.9	36.3	34.8
	22	73.4	67.4	62.4	58.2	54.5	51.3	48.5	46.0	43.7	41.7	39.8	38.1	36.5
I	23	77.8	71.1	65.8	61.2	57.[illegible]	[illegible]	50.9	48.3	45.9	43.7	41.7	39.9	38.3
	24	82.6	75.0	69.2	64.3	60.2	56.6	53.4	50.6	48.0	45.7	43.7	41.8	40.1
C	25		79.2	72.8	67.5	63.1	59.2	55.9	52.9	50.2	47.8	45.6	43.7	41.9
R	26		83.9	76.5	70.8	66.0	62.0	58.4	55.3	52.4	49.9	47.6	45.6	43.7
	27			80.5	74.2	69.1	64.7	61.0	57.7	54.7	52.0	49.6	47.5	45.5
C	28			85.1	77.8	72.2	67.6	63.6	60.1	57.0	54.2	51.7	49.4	47.3
	29				81.7	75.5	70.5	66.3	62.6	59.3	56.4	53.7	51.3	49.1
V	30				86.4	79.0	[illegible]	69.0	65.1	61.6	58.6	[illegible]	53.3	51.0
O	31					82.8	76.7	71.8	67.7	64.0	60.8	57.9	55.3	52.9
	32						80.1	74.8	70.3	66.5	63.1	60.0	57.3	54.8
L	33						83.8	77.8	73.1	69.0	65.4	62.2	59.3	56.7
	34							81.1	75.9	71.5	67.7	64.4	61.4	58.7
T	35							84.8	78.9	74.2	70.1	66.6	63.5	60.6
	36								82.1	76.9	72.6	68.9	65.6	62.7
	37								85.8	79.8	75.2	71.3	67.8	64.7
R	38									83.0	77.9	73.7	70.0	66.8
	39									[illegible]	80.7	76.2	72.3	68.9
E	40										83.8	78.8	74.6	71.0
A	41											81.5	77.1	73.2
	42											84.6	79.6	75.5
D	43												82.3	77.9
	44												85.4	80.4
I	45													83.1
N	46													86.2
	47													
G	48													
	49													
	50													
	51													
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PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 27.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.8	2.6	2.5	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5
	2	5.7	5.3	5.0	4.7	4.4	4.2	3.9	3.8	3.6	3.4	3.3	3.1	3.0
	3	8.6	8.0	7.5	7.0	6.6	6.2	5.9	5.6	5.4	5.1	4.9	4.7	4.5
	4	11.5	10.7	10.0	9.4	8.8	8.4	7.9	7.5	7.2	6.9	6.6	6.3	6.1
	5	14.4	13.4	12.5	11.7	11.1	10.5	9.9	9.4	9.0	8.6	8.2	7.9	7.6
	6	17.3	16.1	15.1	14.1	13.3	12.6	11.9	11.4	10.8	10.3	9.9	9.5	9.1
	7	[illegible]	[illegible]	17.6	16.5	15.6	14.7	14.0	13.3	12.7	12.1	11.6	11.1	10.7
	8	[illegible]	21.6	[illegible]	18.9	17.9	16.9	16.0	15.2	14.5	13.8	13.2	12.7	12.2
	9	[illegible]	24.4	22.8	21.4	20.1	19.0	18.0	17.1	16.3	15.6	14.9	14.3	13.7
	10	29.3	[illegible]	25.4	[illegible]	22.4	21.2	20.1	19.1	18.2	17.4	16.6	15.9	15.3
	11	[illegible]	30.1	[illegible]	26.3	24.8	23.4	22.2	21.1	20.1	19.2	18.3	17.6	16.9
	12	[illegible]	32.9	[illegible]	[illegible]	27.1	25.6	24.2	23.0	21.9	20.9	20.0	19.2	18.4
	13	[illegible]	[illegible]	[illegible]	31.3	29.4	27.8	26.3	25.0	23.8	22.7	21.7	20.8	20.0
	14	41.8	[illegible]	[illegible]	33.8	31.8	30.0	28.4	27.0	25.7	24.5	23.5	22.5	21.6
	15	[illegible]	41.7	[illegible]	36.4	34.2	32.3	30.6	29.0	27.6	26.4	25.2	24.1	23.2
	16	46.2	44.7	41.6	38.9	36.6	34.5	32.7	31.0	29.5	28.2	26.9	25.8	24.8
	17	51.5	47.7	44.4	41.5	39.0	36.8	34.8	33.1	31.5	30.0	28.7	27.5	26.4
	18	54.9	50.8	47.2	44.2	41.5	39.1	37.0	35.1	33.4	31.9	30.5	29.2	28.0
	19	[illegible]	53.9	[illegible]	46.6	44.0	41.4	39.2	37.2	35.4	33.7	32.2	30.9	29.6
	20	61.9	57.1	53.0	49.[illegible]	46.5	43.8	41.4	39.3	37.3	35.6	34.0	32.6	31.2
M	21	[illegible]	[illegible]	56.0	52.[illegible]	49.0	46.1	43.6	41.4	39.3	37.5	35.8	34.3	32.9
	22	[illegible]	[illegible]	59.0	55.0	51.6	48.5	45.9	43.5	41.3	39.4	37.6	36.0	34.5
I	23	73.0	67.0	62.1	57.[illegible]	54.2	51.0	48.1	45.6	43.3	41.3	39.4	37.7	36.2
	24	77.1	70.5	65.2	60.7	56.8	53.4	50.4	47.8	45.4	43.2	41.3	39.5	37.8
C	25	81.5	74.2	68.4	63.6	59.5	55.9	52.7	49.9	47.4	45.2	43.1	41.2	39.5
R	26	86.9	78.1	71.8	66.6	62.2	58.4	55.1	52.1	49.5	47.1	45.0	43.0	41.2
	27		82.2	75.2	69.7	65.0	61.0	57.5	54.4	51.6	49.1	46.8	44.8	42.9
O	28			78.9	72.8	67.8	63.6	59.9	56.6	53.7	51.1	48.7	46.6	44.6
	29			82.9	76.1	70.8	66.2	62.3	58.9	55.8	53.1	50.6	48.4	46.3
V	30				79.6	73.8	69.0	64.8	61.2	58.0	55.1	52.5	50.2	48.1
O	31				83.5	77.0	71.8	67.4	63.6	60.2	57.2	54.5	52.0	49.8
	32					80.3	74.7	70.0	66.0	62.4	59.3	56.5	53.9	51.6
L	33					84.0	77.7	72.7	68.4	64.7	61.4	58.5	55.8	53.4
	34						80.9	75.5	70.9	67.0	63.6	60.5	57.7	55.2
T	35						84.5	78.4	73.5	69.4	65.7	62.5	59.6	57.0
	36							81.5	76.2	71.8	68.0	64.6	61.6	58.8
	37							85.0	79.0	74.3	70.2	66.7	63.5	60.7
R	38								82.0	76.9	72.6	68.9	65.5	62.6
	39								85.4	79.6	75.0	71.1	67.6	64.5
E	40									82.5	77.5	73.3	69.7	66.4
A	41									85.8	80.1	75.6	71.8	68.4
	42										82.9	78.1	74.0	70.4
D	43										86.2	80.6	76.2	72.5
	44											83.3	78.6	74.6
I	45											86.5	81.0	76.8
N	46												83.7	79.1
	47												86.9	81.5
G	48													84.1
	49													87.3
	50													
	51													
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PREDICTED WATER POTENTIAL

[illegible] TIME IN [illegible] MIN ---------- [illegible]
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 29.0

OFFSET FROM ZERO IN MICROVOLTS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
							MATRIX POTENTIAL, NEGATIVE BARS						
	[illegible]	[illegible]	2.4	2.2	2.1	[illegible]	[illegible]	1.8	1.7	[illegible]	1.6	1.5	1.4
	[illegible]	5.1	4.7	4.4	[illegible]	[illegible]	3.8	3.6	3.4	3.3	3.1	3.0	2.9
	[illegible]	7.6	7.1	[illegible]	6.3	[illegible]	5.6	5.4	5.1	4.9	4.7	4.5	4.3
	[illegible]	10.2	[illegible]	8.9	8.4	7.9	7.5	7.2	6.8	6.5	[illegible]	[illegible]	[illegible]
	[illegible]	12.8	[illegible]	11.2	10.5	10.0	9.4	9.0	8.6	8.2	7.8	7.5	7.2
	[illegible]	15.3	14.3	13.5	12.7	12.0	11.4	10.8	10.3	9.8	9.4	9.0	8.7
7	[illegible]	18.0	16.8	15.7	[illegible]	14.0	13.3	12.6	12.0	11.5	11.0	10.5	10.1
	[illegible]	[illegible]	19.2	18.0	17.0	16.0	15.2	14.5	13.8	13.1	12.6	12.1	11.6
	[illegible]	23.2	21.7	20.3	19.2	18.1	17.1	16.3	15.5	14.8	14.2	13.6	13.0
	27.9	[illegible]	24.2	[illegible]	21.3	20.2	19.1	18.1	17.3	16.5	15.8	15.1	14.5
	[illegible]	28.6	26.7	25.0	23.5	22.2	21.1	20.0	19.0	18.2	17.4	16.7	16.0
	[illegible]	31.3	29.2	27.4	25.8	24.3	23.0	21.9	20.8	19.9	[illegible]	18.2	17.5
	[illegible]	34.1	[illegible]	29.7	28.0	26.4	25.0	23.7	22.6	21.6	20.6	19.8	19.0
14	[illegible]	36.8	34.3	32.1	30.2	28.5	27.0	25.6	24.4	23.3	22.3	21.3	20.5
	42.8	39.6	36.9	34.6	32.5	30.6	29.0	27.5	26.2	25.0	23.9	22.9	22.0
16	45.8	42.4	[illegible]	37.0	34.8	32.8	31.0	29.4	28.0	26.7	25.6	24.5	23.5
	48.9	[illegible]	42.2	[illegible]	37.1	34.9	33.1	31.4	29.8	28.5	27.2	26.1	25.0
18	52.1	48.2	[illegible]	41.9	39.4	37.1	35.1	33.3	31.7	30.2	[illegible]	27.6	26.5
	[illegible]	51.1	47.5	44.4	41.7	39.3	37.2	35.3	33.5	32.0	30.5	29.2	28.1
	[illegible]	54.1	50.3	46.9	44.1	41.5	39.2	37.2	35.4	33.7	32.2	30.9	29.6
	61.9	57.1	53.0	[illegible]	46.4	43.7	41.3	39.2	37.3	35.5	33.9	32.5	31.1
22	[illegible]	60.2	55.8	52.1	48.8	46.0	43.4	41.2	39.1	37.3	35.6	34.1	32.7
	[illegible]	63.3	58.7	54.7	51.3	48.2	45.6	43.2	41.0	39.1	37.3	35.7	34.2
24	[illegible]	66.6	61.6	57.4	53.7	50.5	47.7	45.2	42.9	40.9	39.1	37.4	[illegible]
25	[illegible]	69.9	64.6	60.1	56.2	52.9	[illegible]	47.2	44.9	42.7	40.8	[illegible]	37.4
	[illegible]	73.3	67.6	62.8	58.8	55.2	52.1	49.3	46.8	44.6	42.5	40.7	39.0
	[illegible]	76.9	70.7	65.7	61.3	57.6	54.3	51.4	48.8	[illegible]	44.3	[illegible]	40.6
		80.7	74.0	[illegible]	64.0	60.0	56.5	53.5	50.7	48.3	46.1	44.0	42.2
		85.0	77.4	71.5	66.6	62.5	58.8	55.6	52.7	50.2	47.8	45.7	43.8
			81.0	74.6	69.4	65.0	61.1	57.8	54.8	52.1	49.6	47.4	45.4
			85.0	77.8	72.2	[illegible]	63.5	[illegible]	56.8	54.0	51.5	49.2	47.1
32				81.2	75.1	70.1	65.9	62.1	58.9	[illegible]	53.3	[illegible]	48.7
				85.0	78.1	72.8	68.3	64.4	61.0	57.9	55.1	52.6	50.4
34					81.4	75.6	70.8	66.7	63.1	59.9	57.0	54.4	52.1
					[illegible]	78.5	73.4	69.0	65.2	61.9	58.9	56.2	53.8
						81.6	76.0	71.4	67.4	63.9	[illegible]	[illegible]	55.5
37						85.0	78.8	73.9	69.7	66.0	62.7	59.8	57.2
							81.7	76.4	72.0	68.1	64.7	61.7	58.9
							85.0	[illegible]	74.3	70.3	66.7	63.5	60.7
								81.9	76.8	72.5	68.7	65.4	62.5
41								[illegible]		[illegible]	[illegible]	67.4	[illegible]
									82.0	77.1	72.9	69.3	66.1
									85.0	79.5	75.1	71.3	68.0
44										82.1	77.4	73.4	69.9
										85.0	79.7	75.5	71.8
											82.2	77.7	73.8
47											85.0	79.9	75.8
												82.3	77.9
												84.9	80.1
													82.4
													84.9

| | | |

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 31.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
1	2.6	2.4	2.2	2.1	[illegible]	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4
2	5.2	4.[illegible]	4.[illegible]	4.2	4.0	3.8	3.6	3.4	3.2	3.1	3.0	2.8	2.7
3	[illegible]	[illegible]	[illegible]	6.4	[illegible]	5.7	5.4	5.1	4.9	4.6	4.4	4.3	4.1
4	10.4	9.7	9.1	8.5	8.0	7.6	7.2	6.8	6.5	6.2	5.9	5.7	5.5
	13.[illegible]	12.2	11.4	10.7	10.0	9.5	[illegible]	8.5	8.1	7.8	7.4	7.1	6.8
7	[illegible]	14.6	13.7	12.8	12.1	11.4	10.8	10.3	9.8	9.3	8.9	8.6	8.2
8	18.4	17.1	16.0	15.0	14.1	13.3	12.6	[illegible]	11.4	10.9	10.4	10.0	9.6
8	21.1	19.6	18.3	17.2	16.2	15.3	14.5	13.8	13.1	12.5	12.0	11.5	11.0
9	[illegible]	22.1	20.7	[illegible]	18.2	17.2	16.3	15.5	14.8	14.1	13.5	12.9	12.4
1	[illegible]	24.7	23.0	21.6	20.3	19.2	18.2	17.3	16.4	15.7	15.0	14.4	13.8
11	[illegible]	27.2	25.4	23.8	22.4	21.1	20.0	19.0	18.1	17.3	16.5	15.8	15.2
12	[illegible]	29.8	27.8	26.0	24.5	23.1	21.9	20.8	19.8	18.9	18.1	17.3	16.6
13	35.[illegible]	32.4	30.2	28.3	26.6	25.1	23.8	22.6	21.5	20.5	19.6	18.8	18.0
14	37.[illegible]	[illegible]	32.6	30.6	28.7	27.1	25.7	24.4	23.2	22.1	21.2	20.3	19.5
15	4[illegible].7	37.7	35.1	32.9	30.9	29.1	27.6	26.2	24.9	23.8	22.7	21.8	20.9
16	4[illegible].6	40.3	37.6	35.2	33.0	31.2	29.5	28.0	26.6	25.4	24.3	23.3	22.3
17	4[illegible].5	43.0	40.1	37.5	35.2	33.2	31.4	29.8	28.4	27.0	25.8	24.8	23.7
18	49.[illegible]	45.8	42.6	39.8	37.4	35.3	33.3	31.6	30.1	28.7	27.4	26.3	25.2
19	[illegible]	48.[illegible]	45.1	42.2	39.[illegible]	37.3	35.3	33.5	31.8	30.4	29.0	27.8	26.6
2[illegible]	55.[illegible]	51.3	47.7	44.6	41.8	39.4	37.3	35.3	33.6	32.0	30.6	29.3	28.1
N 21	[illegible]	54.2	50.3	47.0	44.1	41.5	39.2	37.2	35.4	33.7	32.2	30.8	29.6
22	[illegible]	57.0	52.9	49.4	46.3	43.6	41.2	39.1	37.1	35.4	33.8	32.4	31.0
I 2[illegible]	[illegible]	60.0	55.6	51.9	48.6	45.8	43.2	41.0	38.9	37.1	35.4	33.9	32.5
24	[illegible]	62.9	58.3	54.4	50.9	47.9	45.2	42.9	40.7	38.8	37.0	35.4	34.0
C 25	71.9	66.0	61.1	56.9	53.3	50.1	47.3	44.8	42.5	40.5	38.7	37.0	35.5
R 26	[illegible]	69.1	63.9	[illegible]	55.6	52.3	49.3	46.7	44.4	42.3	40.3	38.6	37.0
27	79.3	72.4	66.8	62.1	[illegible]	54.5	51.4	48.7	46.2	44.0	42.0	40.2	38.5
O 28	[illegible]	75.7	69.7	64.7	60.5	56.8	53.5	50.6	48.1	45.8	43.7	41.7	40.0
29		79.3	72.7	67.4	62.9	59.1	55.6	52.6	49.9	47.5	45.3	43.3	41.5
V 30		83.1	75.9	70.2	65.5	61.4	57.8	54.6	51.8	49.3	47.0	44.9	43.0
O 31			79.2	73.1	68.0	63.7	60.0	56.7	53.7	51.1	48.7	46.6	44.6
32			82.8	76.1	70.7	66.1	62.2	58.7	55.7	52.9	50.4	48.2	46.1
I 33			87.1	79.2	73.4	68.6	64.4	60.8	57.6	54.7	52.2	49.8	47.7
34				82.5	76.2	71.1	66.7	62.9	59.6	56.6	53.9	51.5	49.3
T 35				86.4	79.1	73.6	69.0	65.1	61.6	58.5	55.7	53.2	50.9
36					82.3	76.3	71.4	67.3	63.6	60.4	57.5	54.8	52.5
37					85.8	79.1	73.9	69.5	65.7	62.3	59.3	56.5	54.1
R 38						82.1	76.4	71.8	67.8	64.2	61.1	58.3	55.7
39						85.3	79.1	74.1	69.9	66.2	62.9	60.0	57.3
E 40							81.9	76.5	72.1	68.2	64.8	61.7	59.0
A 41							84.9	79.0	74.3	70.2	66.7	63.5	60.7
42								81.7	76.6	72.3	68.6	65.3	62.4
D 43								84.6	79.0	74.5	70.6	67.1	64.1
44									81.5	76.7	72.6	69.0	65.8
I 45									84.3	79.0	74.6	70.9	67.6
N 46									87.6	81.4	76.8	72.8	69.4
47										84.0	79.0	74.8	71.2
G 48										87.0	81.3	76.8	73.0
49											83.7	78.9	74.9
50											86.5	81.1	76.9
51												83.5	78.9
52												86.1	81.0
53													83.3
54													85.7
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PSYCHROMETER TEMPERATURE, CENTIGRADE ---

-20 -10

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 33.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-50		-30	-20	-10		+10		+30	+40		+60
1	[illegible]	2.3	2.1	[illegible]	1.9	[illegible]	1.7	1.6	1.5	1.5	1.4	1.4	1.3
[illegible]	3.9	[illegible]	4.3	[illegible]	3.8	3.6	3.4	3.2	3.1	2.9	2.8	2.7	2.6
[illegible]	7.4	6.9	6.5	6.1	5.7	5.4	5.1	4.9	4.6	4.4	4.2	4.1	3.9
4	[illegible]	[illegible]	[illegible]	8.1	7.6	7.2	[illegible]	6.5	6.2	5.9	5.7	5.4	5.2
	[illegible]	11.6	[illegible]	10.2	9.6	9.0	[illegible]	8.1	7.8	7.4	7.1	6.8	6.5
[illegible]	[illegible]	[illegible]	13.0	12.2	11.5	10.9	10.3	9.8	9.3	8.9	8.5	8.2	7.8
7	[illegible]	16.3	[illegible]	14.3	13.5	12.7	12.0	11.4	10.9	10.4	10.0	9.5	9.2
[illegible]	[illegible]	18.7	17.5	16.4	15.4	14.6	[illegible]	13.1	12.5	11.9	11.4	10.9	10.5
[illegible]	22.7	21.1	19.7	18.5	17.4	16.4	15.5	14.8	14.1	13.4	12.8	12.3	11.8
[illegible]	25.3	23.5	21.9	20.6	19.4	18.3	17.3	16.4	15.7	14.9	14.3	13.7	13.1
11	[illegible]	[illegible]	24.2	22.7	21.3	20.1	19.1	18.1	17.3	16.5	15.7	15.1	14.5
12	[illegible]	28.4	26.5	24.8	[illegible]	22.0	20.9	19.8	18.9	18.0	17.2	16.5	15.8
13	33.3	30.9	28.8	26.9	25.3	23.9	22.6	21.5	20.5	19.5	18.7	17.9	17.2
14	36.0	33.3	31.1	29.1	27.4	[illegible]	24.4	23.2	22.1	21.1	20.1	19.3	18.5
[illegible]	38.7	35.9	33.4	31.3	29.4	27.7	26.2	24.9	23.7	22.6	21.6	20.7	19.9
[illegible]	41.4	38.4	[illegible]	[illegible]	31.4	29.7	28.1	26.6	25.3	24.2	23.1	22.1	21.2
17	44.2	40.9	38.1	[illegible]	33.5	31.6	29.9	28.4	27.0	25.7	24.6	23.6	22.6
18	47.0	43.5	40.5	37.9	35.6	33.5	31.7	30.1	28.6	27.3	26.1	25.0	24.0
[illegible]	[illegible]	46.1	[illegible]	[illegible]	37.7	35.5	33.6	31.8	30.3	28.9	27.6	26.4	25.3
[illegible]	52.8	48.8	45.3	42.4	39.8	37.5	35.4	33.6	32.0	30.5	29.1	27.9	26.7
[illegible]	[illegible]	51.4	[illegible]	44.6	41.9	[illegible]	37.3	35.4	33.6	32.1	30.6	29.3	28.1
[illegible]	[illegible]	54.1	50.3	46.9	44.0	41.5	39.2	37.1	35.3	33.7	32.1	30.8	29.5
[illegible]	61.7	56.9	52.8	49.2	46.2	[illegible]	41.1	38.9	37.0	35.3	33.7	32.2	30.9
[illegible]	64.[illegible]	59.7	55.3	51.6	48.4	45.5	43.0	40.7	38.7	36.9	35.2	33.7	32.3
[illegible]	[illegible]	62.5	[illegible]	54.0	50.6	47.6	44.9	42.6	40.4	[illegible]	36.8	35.2	[illegible]
[illegible] 26	71.2	65.4	60.5	56.4	52.8	[illegible]	46.9	44.4	42.2	40.1	38.3	36.7	35.1
27	74.6	68.4	[illegible]	58.8	55.0	51.7	48.8	46.2	43.9	41.8	39.9	38.2	36.6
[illegible]	78.[illegible]	71.4	65.9	61.3	57.3	53.8	50.8	48.1	45.6	43.5	41.5	39.7	38.0
[illegible]	[illegible]	74.6	68.7	63.8	59.6	56.0	52.8	49.9	47.4	45.1	43.0	41.2	39.4
V [illegible]	[illegible].4	77.9	71.5	66.4	62.0	58.1	54.8	51.8	49.2	46.8	44.6	42.7	40.9
[illegible] 31		81.4	74.5	69.0	64.3	60.3	56.8	53.7	51.0	[illegible]	46.2	44.2	42.3
[illegible]		[illegible]	77.6	71.7	66.8	62.6	[illegible]	55.7	52.8	50.2	47.9	45.7	43.8
L 33			80.8	74.4	69.2	64.8	61.0	57.6	54.6	51.9	49.5	47.3	45.3
34			84.4	77.3	71.8	67.1	63.1	[illegible]	[illegible]	53.7	51.1	48.8	46.8
T [illegible]				80.4	74.4	69.5	65.3	61.6	58.3	55.4	52.8	50.4	48.3
[illegible]				83.6	77.1	71.9	67.4	63.6	60.2	57.2	54.5	52.0	49.8
[illegible]				87.7	79.9	74.3	69.7	65.6	62.1	59.0	56.1	53.6	51.3
R [illegible]					83.0	76.9	72.0	67.7	64.0	60.8	57.8	55.2	52.8
[illegible]					86.5	79.6	74.3	69.9	66.0	62.6	59.6	56.8	54.3
F [illegible]						[illegible]	76.7	72.0	68.0	[illegible]	61.3	58.4	[illegible]
A 41						[illegible]	[illegible]	74.3	[illegible]	[illegible]	[illegible]	60.1	57.4
42							[illegible]	76.6	72.1	[illegible]	64.8	61.8	[illegible]
[illegible]							84.8	79.0	74.2	70.2	66.6	63.5	60.6
44								[illegible]	76.4	72.2	68.5	65.2	62.2
[illegible]								84.2	78.7	74.2	70.3	66.9	63.8
M 47								87.4	81.1	76.3	72.2	68.7	[illegible]
47									83.6	78.5	74.2	70.5	67.2
[illegible]									86.5	80.7	76.2	72.3	68.9
[illegible]										83.1	78.2	74.2	70.6
50										85.7	80.4	76.1	72.3
51											82.6	78.0	74.1
52											85.1	80.1	76.0
[illegible]												82.2	77.9
54												84.5	79.8
[illegible]												[illegible]	81.9
56													84.0
57													86.5
[illegible]													
62													
63													
[illegible]													
65													
66													
67													
68													
[illegible]													

											1.4	1.	
4	9.7				7.5			.4					
										7.			
									.1				
			4.9	14.					10.				
			.7.1	16.0	15.0	14.2							
			.9.2	18.0	17.0	16.0		14.4		13.1			
10	.4		1.4	20.1	18.9	17.8							
				22.1	20.8								
12													
		0.1	28.1										
			30.3	28.4	26.7								
			32.6										
16		37.5			30.7			26.0				1.	
17		39.9	37.2					.7.7					
		42.4	39.5										
		45.0	41.8	39.1				1.1					
				41.3									
21		50.1	46.6	43.5									
	57.2	52.8		45.8									
	60.1					4.4	40.1						
	63.1				47.1	44.4	41.9						
	66.1	60.9	56.4		49.3	46.4	43.8						
26	69.3				51.4	46.4	45.7	43.3	41.1				
				57.3	53.6		47.6				.9		
			64.1	59.7	55.8		49.5		44.5				7.1
29	79.4	72.4		62.1	58.1								
		75.6					53.4						
		78.8		67.1			55.4						
			75.3	69.7			57.4						
			85.1										
				80.9	4.8		65.						
				84.1	7.5						54		
					0.3								
								67.5	64.				
41													
							79.						
43													
44													
46										74.1			
47													
											74.0	7.	
55													
61													
69													

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 35.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.4	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2
	2	4.7	4.4	4.1	3.9	3.6	3.4	3.3	3.1	2.9	2.8	2.7	2.6	2.5
	3	7.1	6.6	6.2	5.8	5.5	5.2	4.9	4.6	4.4	4.2	4.0	3.9	3.7
	4	9.5	8.8	8.2	7.7	7.3	6.9	6.5	6.2	5.9	5.6	5.4	5.2	5.0
	5	11.9	11.1	10.3	9.7	9.1	8.6	8.2	7.8	7.4	7.1	6.8	6.5	6.2
	6	14.3	13.3	12.4	11.7	11.0	10.4	9.8	9.3	8.9	8.5	8.1	7.8	7.5
	7	16.6	15.6	14.5	13.6	12.8	12.1	11.5	10.9	10.4	9.9	9.5	9.1	8.7
	8	19.2	17.6	16.7	15.6	14.7	13.9	13.2	12.5	11.9	11.4	10.9	10.4	10.0
	9	21.7	20.1	18.8	17.6	16.6	15.7	14.8	14.1	13.4	12.8	12.3	11.7	11.3
	10	24.2	22.4	20.9	19.6	18.5	17.4	16.5	15.7	14.9	14.3	13.6	13.1	12.5
	11	26.7	24.7	23.1	21.6	20.4	19.2	18.2	17.3	16.5	15.7	15.0	14.4	13.8
	12	29.2	27.1	25.2	23.7	22.3	21.0	19.9	18.9	18.0	17.2	16.4	15.7	15.1
	13	31.7	29.4	27.4	25.7	24.2	22.8	21.6	20.5	19.5	18.6	17.8	17.1	16.4
	14	34.3	31.8	29.6	27.7	26.1	24.6	23.3	22.1	21.1	20.1	19.2	18.4	17.7
	15	36.9	34.2	31.8	29.8	28.0	26.4	25.0	23.8	22.6	21.6	20.6	19.8	19.0
	16	39.5	36.6	34.1	31.9	30.0	28.3	26.8	25.4	24.2	23.1	22.0	21.1	20.3
	17	42.1	39.0	36.3	34.0	31.9	30.1	28.5	27.0	25.7	24.5	23.5	22.5	21.6
	18	44.7	41.4	38.6	36.1	33.9	32.0	30.2	28.7	27.3	26.0	24.9	23.8	22.9
	19	47.4	43.9	40.8	38.2	35.9	33.8	32.0	30.3	28.9	27.5	26.3	25.2	24.2
	20	50.2	46.4	43.1	40.3	37.9	35.7	33.8	32.0	30.5	29.0	27.7	26.6	25.5
M	21	52.9	48.9	45.5	42.5	39.9	37.6	35.5	33.7	32.0	30.5	29.2	27.9	26.8
	22	55.7	51.4	47.8	44.6	41.9	39.5	37.3	35.4	33.6	32.1	30.6	29.3	28.1
I	23	58.5	54.0	50.2	46.8	43.9	41.4	39.1	37.1	35.2	33.6	32.1	30.7	29.5
	24	61.4	56.6	52.6	49.0	46.0	43.3	40.9	38.8	36.9	35.1	33.6	32.1	30.8
C	25	64.4	59.3	55.0	51.3	48.1	45.2	42.7	40.5	38.5	36.7	35.0	33.5	32.1
R	26	67.4	62.0	57.4	53.5	50.2	47.2	44.6	42.2	40.1	38.2	36.5	34.9	33.5
	27	70.5	64.7	59.9	55.8	52.3	49.2	46.4	44.0	41.8	39.8	38.0	36.3	34.8
O	28	73.7	67.6	61.9	58.1	54.4	51.2	48.3	45.7	43.4	41.4	39.5	37.8	36.2
	29	77.0	70.4	65.0	60.8	56.6	53.2	50.2	47.5	45.1	42.9	41.0	39.2	37.6
V	30	80.6	73.4	67.7	62.9	58.8	55.2	52.1	49.3	46.8	44.5	42.5	40.6	38.9
O	31	84.5	76.5	70.4	65.3	61.0	57.3	54.0	51.1	48.5	46.1	44.0	42.1	40.3
	32		79.7	73.1	67.8	63.3	59.3	55.9	52.9	50.2	47.7	45.5	43.5	41.7
L	33		83.3	76.0	70.3	65.6	61.5	57.9	54.7	51.9	49.4	47.1	45.0	43.1
	34		87.5	79.0	72.9	67.9	63.6	59.9	56.6	53.6	51.0	48.6	46.5	44.5
T	35			82.2	75.6	70.3	65.8	61.9	58.4	55.4	52.6	50.2	47.9	45.9
	36			85.8	78.4	72.7	68.0	63.9	60.3	57.1	54.3	51.7	49.4	47.3
	37				81.4	75.2	70.2	66.0	62.2	58.9	56.0	53.3	50.9	48.7
R	38				84.6	77.9	72.5	68.1	64.2	60.7	57.7	54.9	52.4	50.2
	39					80.6	74.9	70.2	66.1	62.6	59.4	56.5	54.0	51.6
E	40					83.6	77.4	72.4	68.1	64.4	61.1	58.2	55.5	53.1
A	41					87.0	79.9	74.6	70.2	66.3	62.9	59.8	57.0	54.5
	42						82.7	77.0	72.2	68.2	64.6	61.5	58.6	56.0
D	43						85.7	79.4	74.4	70.1	66.4	63.1	60.2	57.5
	44							81.9	76.6	72.1	68.3	64.8	61.8	59.0
I	45							84.7	78.8	74.1	70.1	66.6	63.4	60.5
N	46								81.2	76.2	72.0	68.3	65.0	62.1
	47								83.8	78.4	73.9	70.1	66.7	63.6
G	48								86.7	80.6	75.9	71.9	68.4	65.2
	49									83.0	78.0	73.7	70.1	66.8
	50									85.6	80.1	75.6	71.8	68.4
	51										82.3	77.6	73.6	70.0
	52										84.7	79.6	75.4	71.7
	53										87.6	81.7	77.2	73.4
	54											83.9	79.1	75.1
	55											86.5	81.1	76.9
	56												83.2	78.7
	57												85.5	80.6
	58													82.6
	59													84.8
	60													87.2
	61													
	62													
	63													
	64													
	65													
	66													
	67													
	68													
	69													
	70													

COOLING TIME IN SECONDS -
PSYCHROMETER TEMPERATURE, 36.0

	1								1.6					
	2	4	3	4.0										
	3	6.9	6.5		5.7		5.0				4.1			
	4		8.6	8.1	.6		6.7	6.4						
	5	11.6	10.8	10.1			8.4				6.9			
	6	14		12.1	11	10.7			9.1			7.9		
	7	16.4	2	4.			11.9		10.7		9.7			
	8	1	17 4	16.3		14.4	13.6			11.6	11.1			
	9		19 7	18.4	17 2	16.		14.5						
	10		21				17.0					16.3		
	11		4 2	22.5	21 1	19.9	18.8	17.8	16.9	16.1		14.7	14.1	13.5
	12	5	26 4	24.7	1	21.7		19.4			16.8			4
	13	31.	7	26.8	1		22.3			19.1				
	14	5	1.	28.9	27 1	25.5	24.0	22.8		20.6				
	15	36.	.4	31.1	29 1	27.4				22.1	21.1			
	16		7	33.3	31 1		27.6	26.1						
	17	41 1		4		31.2	29.4	27.8		25.1				
	18	7	4 4	37.6		33.1					25.4			
	19	46.		39.9	3	35.0	33.0							
	20	9		42.1	4	37.0			31.3					
N	21		47.7		4.	38.9	36.7	34.7						
	22	54		46.6		40.9		36.4						
I	23	57 1	32 7	48.9	45 7		40.4			34.4				
	24			51.3	9			39.9						
	25	7	57.	53.6				41.7		37.6		34.2		
F	26	6	4	56.0		48.9	46.1	43.5	41.2				34.1	
		6	61.1	58.4		51.0	48.0	45.3		40.8				
O	28	71.7	65.	60.9	7	53.1	49.9	47.1		42.4	40.4			
		7		63.4		55.2	51.9	48.9	46.3	44.0	41.9	40.0		
V		78.	71 4	65.9		57.3	53.8	50.8	48.1					
O			4.	68.5		59.5	55.8	52.7		47.3	45.0			
			4	71.1	66	61.6	57.9	54.5		49.0	46.6	44.4		40.7
L					4	63.9	59.9					45.9		
			4.	76.7		66.1	62.0				49.7	47.4		
T				79.7	73 5	68.4		60.3						
						70.7		62.2						
	37					73.1	68.4			57.4				
R	38					75.6	70.6							
	39				0				64.4					
F	40													
A	41					83.8	77.6	7.						
	42					87.2	80.1	74.6						
D	43						82.8							
	44						85.7	79.4	74.4					
I	45									72.1				
N	46									74.1				
	47							87.9	81.1	76.1	71.9			
S	48													
	49									80.4	75.7	71.7		
	50										77.7			
	51													
	52													
	53													71.4
	54													
	55													
	56													
	57													
	58													
	59													
	60													
	61													
	62													
	63													
	64													
	65													
	66													
	67													
	68													
	69													
	70													

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 37.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

	[illegible]	[illegible]	[illegible]	-30	-20	-10	0	+10	+20	[illegible]	+40	+50	[illegible]
1	2.3	2.1	2.0	1.8	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2
2	4.5	4.2	3.9	3.7	3.5	3.3	3.1	3.0	2.8	2.7	2.6	2.5	2.4
3	6.8	6.3	5.9	5.5	5.2	4.9	4.7	4.4	4.2	4.0	3.9	3.7	3.6
4	9.1	8.4	7.9	7.4	7.0	6.6	6.2	5.9	5.7	5.4	5.2	5.0	4.8
5	11.4	10.6	9.9	9.3	8.7	8.2	7.8	7.4	7.1	6.8	6.5	6.2	6.0
[illegible]	13.7	12.7	11.9	11.1	[illegible]	9.9	9.4	8.9	8.5	8.1	7.8	7.5	7.2
7	[illegible]	14.9	[illegible]	[illegible]	[illegible]	11.6	11.0	10.4	9.9	9.5	9.1	8.7	8.4
8	18.3	17.[illegible]	[illegible]	14.9	14.0	13.3	12.6	11.9	11.4	10.9	10.4	10.0	9.6
9	[illegible]	19.[illegible]	17.9	16.8	15.8	15.[illegible]	14.2	13.5	12.8	12.2	11.7	11.2	10.8
10	[illegible]	21.4	[illegible]	[illegible]	17.6	16.7	15.8	15.[illegible]	14.3	13.6	13.[illegible]	12.5	12.0
11	25.4	23.6	22.0	[illegible]	19.4	18.4	17.4	16.[illegible]	15.7	15.0	14.4	13.8	13.2
12	[illegible]	25.8	24.1	[illegible]	21.2	20.1	[illegible]	18.0	17.2	16.4	15.7	15.0	14.4
13	[illegible]	[illegible]	[illegible]	24.5	[illegible]	21.8	[illegible]	19.6	18.7	17.8	17.0	16.3	15.7
14	32.7	[illegible]	[illegible]	26.[illegible]	24.9	[illegible]	[illegible]	21.1	20.1	19.2	18.4	17.6	16.9
15	[illegible]	32.6	[illegible]	[illegible]	26.7	25.2	[illegible]	22.7	21.6	20.6	19.7	18.9	18.1
16	[illegible]	34.9	32.5	[illegible]	[illegible]	[illegible]	25.5	24.2	[illegible]	[illegible]	21.0	20.2	19.4
17	[illegible]	37.2	[illegible]	[illegible]	[illegible]	28.7	[illegible]	25.8	24.6	[illegible]	22.4	21.5	20.6
18	42.6	39.5	[illegible]	34.4	32.[illegible]	[illegible]	[illegible]	27.4	26.1	24.9	23.[illegible]	22.8	21.8
19	[illegible]	41.8	[illegible]	[illegible]	34.[illegible]	[illegible]	[illegible]	29.0	27.6	[illegible]	25.1	24.1	[illegible]
20	47.7	44.2	41.1	[illegible]	36.1	34.0	[illegible]	[illegible]	29.1	27.7	26.5	25.4	24.3
M 21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35.8	33.9	[illegible]	30.6	29.2	27.9	26.7	[illegible]
22	[illegible]	49.[illegible]	45.5	[illegible]	39.[illegible]	37.6	[illegible]	33.8	32.1	30.6	29.2	28.0	[illegible]
I 23	[illegible]	[illegible]	47.8	44.6	41.[illegible]	[illegible]	37.[illegible]	[illegible]	[illegible]	[illegible]	30.6	29.[illegible]	28.1
24	58.4	[illegible]	[illegible]	46.7	43.8	41.3	[illegible]	[illegible]	[illegible]	33.5	[illegible]	[illegible]	29.4
C 25	61.1	56.4	[illegible]	48.[illegible]	45.8	43.1	[illegible]	38.6	36.7	35.0	33.4	32.0	[illegible]
F 26	[illegible]	[illegible]	54.6	51.0	47.8	45.0	42.5	[illegible]	[illegible]	36.5	34.8	33.3	31.9
27	[illegible]	61.5	57.0	53.1	49.8	46.8	44.2	41.9	39.8	37.9	36.2	34.7	33.2
[illegible] 28	69.7	64.1	59.3	[illegible]	51.8	48.7	46.0	43.6	41.4	39.4	37.6	36.0	34.5
29	72.8	[illegible]	61.7	57.[illegible]	[illegible]	[illegible]	47.8	45.[illegible]	43.0	40.9	39.1	37.4	35.8
V 30	[illegible]	[illegible]	64.2	59.7	[illegible]	[illegible]	49.6	46.9	44.6	42.4	40.5	38.7	37.1
O 31	79.[illegible]	72.3	66.7	[illegible]	[illegible]	54.5	51.4	48.6	46.2	44.0	41.9	40.1	38.4
32	[illegible]	75.2	[illegible]	[illegible]	60.1	[illegible]	53.2	50.3	47.8	45.5	43.4	41.5	39.8
L 33	[illegible]	78.2	71.[illegible]	[illegible]	62.2	[illegible]	[illegible]	52.1	[illegible]	47.0	44.9	42.9	41.1
34		81.4	74.6	[illegible]	64.4	[illegible]	56.9	53.8	51.0	[illegible]	46.3	44.3	42.4
T 35		[illegible]	77.4	71.5	[illegible]	[illegible]	58.8	55.6	[illegible]	50.1	47.8	45.7	43.7
[illegible]			[illegible]	74.0	[illegible]	64.5	[illegible]	[illegible]	54.4	51.7	49.3	47.1	45.1
37			83.5	76.6	71.2	66.6	[illegible]	59.1	[illegible]	53.3	[illegible]	48.5	46.4
F 38			[illegible]	79.[illegible]	73.5	[illegible]	[illegible]	[illegible]	57.7	54.9	[illegible]	49.9	47.8
39				[illegible]	76.[illegible]	[illegible]	[illegible]	62.8	[illegible]	[illegible]	[illegible]	51.4	49.2
E 40				85.4	[illegible]	73.1	[illegible]	64.6	61.2	[illegible]	[illegible]	52.8	[illegible]
A 41					81.1	[illegible]	[illegible]	[illegible]	62.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42					[illegible]	[illegible]	72.7	[illegible]	64.7	61.4	[illegible]	55.8	53.3
I 43					[illegible]	80.2	[illegible]	[illegible]	[illegible]	[illegible]	60.0	57.2	54.7
44						[illegible]	77.1	72.4	[illegible]	64.8	[illegible]	[illegible]	[illegible]
I 45						85.8	[illegible]	74.4	70.2	[illegible]	[illegible]	60.2	[illegible]
L 46							81.[illegible]	[illegible]	72.1	68.2	[illegible]	61.8	59.0
47							[illegible]	[illegible]	74.0	[illegible]	[illegible]	63.[illegible]	[illegible]
G 48							[illegible]	[illegible]	76.0	71.[illegible]	[illegible]	64.9	[illegible]
49								[illegible]	78.0	[illegible]	69.8	[illegible]	63.4
50								[illegible]	[illegible]	[illegible]	71.5	[illegible]	64.9
51									82.4	77.5	[illegible]	69.7	[illegible]
52									[illegible]	[illegible]	[illegible]	71.[illegible]	68.[illegible]
[illegible]									[illegible]	81.[illegible]	[illegible]	[illegible]	[illegible]
54										83.8	[illegible]	74.7	71.1
[illegible]										86.3	[illegible]	[illegible]	[illegible]
[illegible]											[illegible]	78.3	74.3
[illegible]											85.1	80.1	[illegible]
58											[illegible]	82.1	77.7
[illegible]												[illegible]	79.5
[illegible]												86.[illegible]	[illegible]
[illegible]													83.3
[illegible]													[illegible]
63													
[illegible]													
[illegible]													
[illegible]													
[illegible]													

METER TEMPERATURE

PREDICTED WATER POTENTIAL

COOLING TIME IN SECONDS ---------- 60.0
PSYCHROMETER TEMPERATURE, CENTIGRADE --- 39.0

OFFSET FROM ZERO IN MICROVOLTS

WATER POTENTIAL, NEGATIVE BARS

		-60	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+60
	1	2.[illegible]	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1
	2	4.[illegible]	4.[illegible]	[illegible].8	3.5	3.3	3.1	3.0	2.8	2.7	2.6	2.5	2.4	2.3
	3	6.[illegible]	6.[illegible]	5.6	5.3	5.0	4.7	4.5	4.3	4.1	3.9	3.7	3.6	3.4
	4	8.7	8.[illegible]	7.5	7.1	6.7	6.[illegible]	6.[illegible]	5.7	5.4	5.2	4.9	4.7	4.6
	5	10.9	10.1	9.4	8.9	8.4	7.9	7.5	7.1	6.8	6.5	6.2	5.9	5.7
	6	13.1	12.2	11.4	10.7	10.0	9.5	9.0	8.5	8.1	7.8	7.4	7.1	6.9
	7	15.3	14.2	13.3	12.5	11.7	11.1	10.5	10.0	9.5	9.1	8.7	8.3	8.0
	8	17.5	16.3	15.2	14.3	13.4	12.7	12.0	11.4	10.9	10.4	10.0	9.5	9.2
	9	19.6	18.4	17.2	16.1	15.1	14.3	13.6	12.9	12.3	11.7	11.2	10.7	10.3
	10	[illegible]	20.5	19.1	17.9	16.9	15.9	15.1	14.3	13.7	13.0	12.5	12.0	11.5
	11	24.3	22.6	21.1	19.7	18.6	17.6	16.6	15.8	15.0	14.4	13.7	13.2	12.6
	12	26.6	24.7	23.0	21.6	20.3	19.2	18.2	17.3	16.4	15.7	15.0	14.4	13.8
	13	28.9	26.8	25.0	23.4	22.1	20.8	19.7	18.7	17.8	17.0	16.3	15.6	15.0
	14	31.2	29.0	27.0	25.3	23.8	22.5	21.3	20.2	19.2	18.4	17.6	16.8	16.2
	15	33.5	31.1	29.0	27.2	25.6	24.1	22.8	21.7	20.7	19.7	18.9	18.1	17.3
	16	35.9	33.3	31.0	29.1	27.3	25.8	24.4	23.2	22.1	21.1	20.1	19.3	18.5
	17	[illegible]	35.5	33.1	31.0	29.1	27.5	26.0	24.7	23.5	22.4	21.4	20.5	19.7
	18	40.7	37.7	35.1	32.9	30.9	29.1	27.6	26.2	24.9	23.8	22.7	21.8	20.9
	19	43.1	39.9	37.2	34.8	32.7	30.8	29.2	27.7	26.4	25.1	24.0	23.0	22.1
	20	45.5	42.1	39.2	36.7	34.5	32.5	30.8	29.2	27.8	26.5	25.3	24.3	23.3
M	21	4[illegible].0	44.4	41.3	38.6	36.3	34.2	32.4	30.7	29.2	27.9	26.6	25.5	24.5
	22	[illegible].5	46.7	43.4	40.6	38.1	35.9	34.0	32.3	30.7	29.3	28.0	26.8	25.7
I	23	[illegible].0	49.0	45.5	42.6	40.0	37.7	35.6	33.8	32.1	30.6	29.3	28.0	26.9
	24	5[illegible].5	51.3	47.7	44.6	41.8	39.4	37.3	35.3	33.6	32.0	30.6	29.3	28.1
C	25	58.1	53.7	49.9	46.6	43.7	41.2	38.9	36.9	35.1	33.4	31.9	30.6	29.3
R	26	[illegible].8	56.0	52.0	48.6	45.6	42.9	40.6	38.5	36.6	34.8	33.3	31.9	30.5
	27	63.5	58.5	54.2	50.6	47.5	44.7	42.2	40.0	38.0	36.3	34.6	33.1	31.8
O	28	[illegible].2	60.9	5[illegible].5	52.7	49.4	46.5	43.9	41.6	39.5	37.7	36.0	34.4	33.0
	29	[illegible].0	63.4	58.8	54.8	51.3	48.3	45.6	43.2	41.0	39.1	37.3	35.7	34.2
V	30	71.9	66.0	61.0	56.9	53.3	50.1	47.3	44.8	42.6	40.5	38.7	37.0	35.5
O	31	74.8	68.5	63.4	59.0	55.2	51.9	49.0	46.4	44.1	42.0	40.1	38.3	36.7
	32	77.9	71.2	65.8	61.2	57.2	53.8	50.7	48.0	45.6	43.4	41.4	39.6	38.0
L	33	81.[illegible]	73.9	68.2	63.4	59.2	55.6	52.5	49.7	47.1	44.9	42.8	41.0	39.2
	34	84.8	76.8	70.6	65.6	61.3	57.5	54.2	51.3	48.7	46.3	44.2	42.3	40.5
T	35		79.8	73.2	67.8	63.3	59.4	56.0	53.0	50.3	47.8	45.6	43.6	41.8
	36		82.9	75.8	70.2	65.4	61.3	57.8	54.6	51.8	49.3	47.0	45.0	43.1
	37		86.6	78.5	72.5	67.6	63.3	59.6	56.3	53.4	50.8	48.4	46.3	44.3
R	38			81.4	75.0	69.7	65.3	61.4	58.0	55.0	52.3	49.9	47.7	45.6
	39			84.6	77.5	72.0	67.3	63.3	59.8	56.6	53.8	51.3	49.0	46.9
E	40				80.1	74.2	69.3	65.2	61.5	58.3	55.4	52.8	50.4	48.2
A	41				82.9	76.6	71.4	67.1	63.3	59.9	56.9	54.2	51.8	49.5
	42				86.1	79.0	73.6	69.0	65.0	61.6	58.5	55.7	53.2	50.9
D	43					81.6	75.8	71.0	66.9	63.2	60.0	57.2	54.6	52.2
	44					84.4	78.1	73.0	68.7	64.9	61.6	58.6	56.0	53.5
I	45					87.7	80.4	75.1	70.6	66.7	63.2	60.2	57.4	54.9
N	46						82.9	77.2	72.5	68.4	64.9	61.7	58.8	56.2
	47						85.7	79.4	74.4	70.2	66.5	63.2	60.3	57.6
G	48							81.7	76.4	72.0	68.2	64.8	61.7	59.0
	49							84.2	78.5	73.9	69.9	66.3	63.2	60.4
	50							87.1	80.7	75.8	71.6	67.9	64.7	61.8
	51								82.9	77.7	73.3	69.6	66.2	63.2
	52								85.4	79.7	75.1	71.2	67.7	64.6
	53									81.8	77.0	72.9	69.3	66.1
	54									84.1	78.9	74.6	70.9	67.5
	55									86.6	80.9	76.3	72.4	69.0
	56										82.9	78.1	74.1	70.5
	57										85.2	80.0	75.7	72.1
	58											81.9	77.4	73.6
	59											84.0	79.2	75.2
	60											86.3	81.0	76.8
	61												82.9	78.5
	62												85.0	80.2
	63												87.4	82.0
	64													83.9
	65													86.0
	66													
	67													
	68													
	69													
	70													

PSYCHROMETER TEMPERATURE

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Brown, Ray W., and Dale L. Bartos.
1982. A calibration model for screen-caged Peltier thermocouple psychrometers. USDA For. Serv. Res. Pap. INT-293, 155 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

A calibration model for screen-caged Peltier thermocouple psychrometers was developed that applies to a water potential range of 0 to -80 bars, over a temperature range of 0° to 40° C, and for cooling times of 15 to 60 seconds. In addition, the model corrects for the effects of temperature gradients over zero-offsets from -60 to +60 microvolts. Complete details of model development are discussed, together with the theory of thermocouple psychrometers, and techniques of calibration and cleaning. Also, information for computer programing and tabular summaries of model characteristics are provided.

KEYWORDS: thermocouple psychrometers, calibration, modeling, water potential, temperature gradient effects, Peltier cooling, screen-caged psychrometers, psychrometer calibration model

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Aspen Community Types on the Caribou and Targhee National Forests in Southeastern Idaho

Walter F. Mueggler and Robert B. Campbell, Jr.

THE AUTHORS

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RESEARCH SUMMARY

A classification system is presented for aspen- *(Populus tremuloides-)* dominated forests on the Caribou and Targhee National Forests in southeastern Idaho. Twenty-three aspen community types are defined and described. A diagnostic key utilizing indicator plant species is provided for field identification of the community types. Vegetational composition, productivity, and successional status are discussed. Tables are provided for detailed comparisons.

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- *Populus tremuloides-Abies lasiocarpa/Thalictrum fendleri* Community Type 11
- *Populus tremuloides-Pseudotsuga menziesii/Amelanchier alnifolia* Community Type 11
- *Populus tremuloides-Pseudotsuga menziesii/Symphoricarpos oreophilus* Community Type 1
- *Populus tremuloides-Pseudotsuga menziesii/Calamagrostis rubescens* Community Type 1
- *Populus tremuloides-Pinus contorta/Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Amelanchier alnifolia-Pachistima myrsinites* Community Type 1
- *Populus tremuloides/Amelanchier alnifolia-Spiraea betulifolia* Community Type 1
- *Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus* Community Type 1
- *Populus tremuloides/Amelanchier alnifolia-Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Pachistima myrsinities-Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Pachistima myrsinites-Geranium viscosissimum* Community Type 1
- *Populus tremuloides/Spiraea betulifolia-Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Symphoricarpos oreophilus-Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Symphoricarpos oreophilus-Poa pratensis* Community Type 1
- *Populus tremuloides/Symphoricarpos oreophilus-Rudbeckia occidentalis* Community Type 1
- *Populus tremuloides/Artemisia tridentata-Festuca idahoensis* Community Type 1
- *Populus tremuloides/Geranium viscosissimum* Community Type 1
- *Populus tremuloides/Wyethia amplexicaulis* Community Type 1
- *Populus tremuloides/Calamagrostis rubescens* Community Type 1
- *Populus tremuloides/Calamagrostis rubescens-Poa pratensis* Community Type 1
- *Populus tremuloides/Poa pratensis* Community Type 1
- *Populus tremuloides/Rudbeckia occidentalis* Community Type 1
- Other Aspen Communities 1

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Ogden, UT 84404**

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July 1982

Aspen Community Types on the Caribou and Targhee National Forests in Southeastern Idaho

Walter F. Mueggler and Robert B. Campbell, Jr.

INTRODUCTION

Aspen (*Populus tremuloides* Michx.) forests within the Intermountain Region span a broad environmental range compared to other major vegetational types. Aspen can be found associated with such divergent types as moist *Picea-Abies* forests and relatively dry *Artemisia*-grass steppes. Within the region it occurs at elevations ranging from 5,000 to 11,000 ft (1 525 to 3 350 m), and on all topographic exposures. In addition, aspen is regarded as both a seral dominant and climax dominant tree, but its successional status on a specific area is often uncertain (Mueggler 1976). The diverse environment suitable for the growth of aspen results in considerable variation in composition of undergrowth vegetation, its productivity, and the potential of aspen communities to produce forage, wildlife habitat, and wood products.

Intensive multiple-use management for the resources produced by aspenlands requires that we be able to categorize the land units according to their potential productivity and probable response to management. Recognition of the need for such wildland classifications has prompted the current thrust in habitat type classification in the West (Pfister 1976). Habitat types are aggregations of land units capable of supporting similar climax plant communities and are based upon species composition of the climax community. Such a classification has recently been completed for the forests of eastern Idaho and western Wyoming (Steele and others, in press), which covers the Caribou and Targhee National Forests. Aspenlands, however, were not treated in detail in this habitat type classification because aspen was primarily considered to be either seral to conifers, or persistently seral with unknown climax potential. Steele and others (in press) did recognize climax aspen communities below the lower limits of conifers in the *Artemisia tridentata* zone, but did not describe these in detail.

The uncertain successional status of many aspen communities renders the habitat-type approach to classifying these communities infeasible at present. A community-type approach, however, is appropriate because it avoids the presumption of climax. Community types are aggregations of similar plant communities based upon existing floristic composition regardless of successional status. Both of these approaches to classification view the plant community as an environmental integrator. Community types may be either climax types or seral types leading to one or more climax types. This existing vegetation is usually what the resource manager must contend with in the field. Once community types are defined, effort can be directed toward linking these types to known habitat types for a better understanding of the successional process. Meanwhile, the community types can be used as a basis for mapping and resource management planning.

An aspen community type classification was recently developed for the Bridger-Teton National Forest in western Wyoming (Youngblood and Mueggler 1981). This classification described 26 community types, of which three were considered climax community types, that is, stable communities representing habitat types. Sixteen were considered seral to climax community types dominated by conifers, and the stability of seven of the types was uncertain. The Caribou and Targhee National Forests border the Bridger-Teton National Forest on the west, and thus were natural candidates for extending the aspen classification work. All three Forests contain sizable acreages of aspen communities intermingled with other vegetation types. The Forests occur mainly within the Middle Rocky Mountain physiographic province (Fenneman 1931), which appears to be a zone of transition for aspen from the sporadic occurrence of small groves in the Northern Rocky Mountains to the extensive stands of aspen in the Colorado Plateau and Southern Rocky Mountain provinces (Mueggler , in press).

The Caribou and Targhee National Forests consist primarily of a sequence of northerly trending mountain ranges (fig. 1); the exceptions to this are the Centennial Range, with an east-west orientation along the northern part of the Targhee Forest and the Yellowstone Plateau. Elevations range from approximately 5,000 ft (1 525 m) along the edge of the Snake River Plains to over 12,000 ft (3 650 m) in the Teton Range. Within this elevational spread, major vegetation zones range from the *Artemisia* steppes on the plains and semiarid portions of lower mountains, through the *Pseudotsuga* and *Abies* coniferous forest zones, to alpine tundra on the highest peaks. Aspen communities are most abundant in this area at elevations between 6,000 and 7,500 ft (1 830 and 2 290 m).

Both the small groves and larger stands of aspen located adjacent to and scattered throughout the predominantly coniferous forests are important components of the vegetational complex of these two National Forests. Aspen-dominated communities are regarded as highly desirable multiple-use areas. They not only provide abundant livestock forage and important habitat for many forms of wildlife, but are esthetically pleasing, offer good watershed protection, and are a potential source of wood fiber.

Our objective was to develop a classification, based upon existing vegetation, for partitioning the natural variability among aspen communities on the Caribou and Targhee Forests. It is hoped that this classification will serve as a tool for improved multiple-use planning and management on these Forests.

METHODS

Species composition data from a large number of aspen stands spanning the environmental range of aspen on the two Forests were required to develop the community type classification. In addition, relatively detailed and time-consuming plot samples were needed to describe productivity, stand structure, and some of the environmental features. We did not have the capability to sample all stands in detail and still obtain sufficient numbers from which to structure a representative classification. Therefore, a dual sampling approach was used; reconnaissance plots were sampled rapidly by one person traveling independently from a two-person crew that sampled the more time-consuming intensive plots. The reconnaissance plots were designed to obtain estimates of species composition along with the more easily obtained environmental parameters. The intensive plots were designed to yield data on stand structure, age, productivity, and environment as well as species composition.

Field Methods

The selection of a stand for sampling, although subjective, was without conscious bias. The selection criteria were to sample the full environmental range of aspen and to sample only stands that were sufficiently large to contain the sample plot within an apparently uniform environment. A stand was considered for sampling if at least 50 percent of the tree canopy cover consisted of aspen. Neither apparent successional status nor grazing intensity were considerations in stand selection. In most cases, locating stands involved traveling forest roads to find reasonably accessable candidate stands.

Once a stand was selected for intensive sampling, a single 1/13-acre (1/32-ha) circular macroplot was established in a relatively uniform and representative portion of the stand. Clonal ecotones were avoided where a stand consisted of more than a single aspen clone, as were the ecotones occurring at stand margins and atypical openings. Tree data determined by species on the entire macroplot consisted of: an ocular estimate of overhead canopy cover; reproduction as number of stems less than 4.0 inches (1 dm), 4.0 to 11.9 inches (1 to 3 dm) and 12 to 55 inches (3 to 14 dm) high; number of stems by 2-inch (5-cm) d.b.h. size classes; and age, height, and diameter of individual trees selected to represent the dominant and other well-defined strata. Species composition of the undergrowth shrubs and herbs was determined by estimates of canopy-cover classes based upon careful overall scrutiny of the entire macroplot. In addition, canopy cover of shrubs, graminoids, forbs, and annuals were estimated separately as vegetational classes. Undergrowth biomass was determined by a combination of estimating and clipping current year's growth of shrubs (below 5 ft [1.5 m] high) and herbs on three sets of plots randomly distributed on the 1/13-acre (1/32-ha) macroplot. Each set of plots consisted of a cluster of five circular 5.4-ft^2 (1/2-m^2) microplots on which the current growth on four was estimated as a percentage of the fifth, which was then clipped. The clipped material was saved and later dried for 48 hours at 158° (70° C). All production values given are dry weights. Production, therefore, was based on 15 microplots per stand. An estimated correction was applied at the time of sampling to adjust for sampling either earlier or later than peak standing crop, as well as to compensate for obvious utilization by livestock. The proportion of the current growth consisting of the different vegetation classes was estimated. The following environmental parameters were determined for each intensively sampled stand: elevation, aspect, percent slope, land form, soil parent material, depth of melanized layer, and estimates of rooting depth, soil rockiness, and soil texture. Evidence of succession, livestock use, and other interpretive information were recorded. A total of 114 stands scattered across the Caribou and Targhee National Forests were sampled in this manner.

The relatively rapid reconnaissance technique involved choosing an approximately 1/10-acre (1/25-ha) portion of the selected stand, avoiding apparent ecotones, and by carefully scrutinizing the area, ocularly estimating the percentage canopy cover of each species as well as the of total shrub, graminoid, and forb classes. Canopy cover of trees was estimated separately for that portion under 5 ft (1.5 m) high (reproduction) and that portion over this height. The environmental parameters of elevation, aspect, landform, and soil parent material were recorded and interpretive information related to apparent succession and animal use was noted. A total of 211 stands were sampled by this method on the two National Forests.

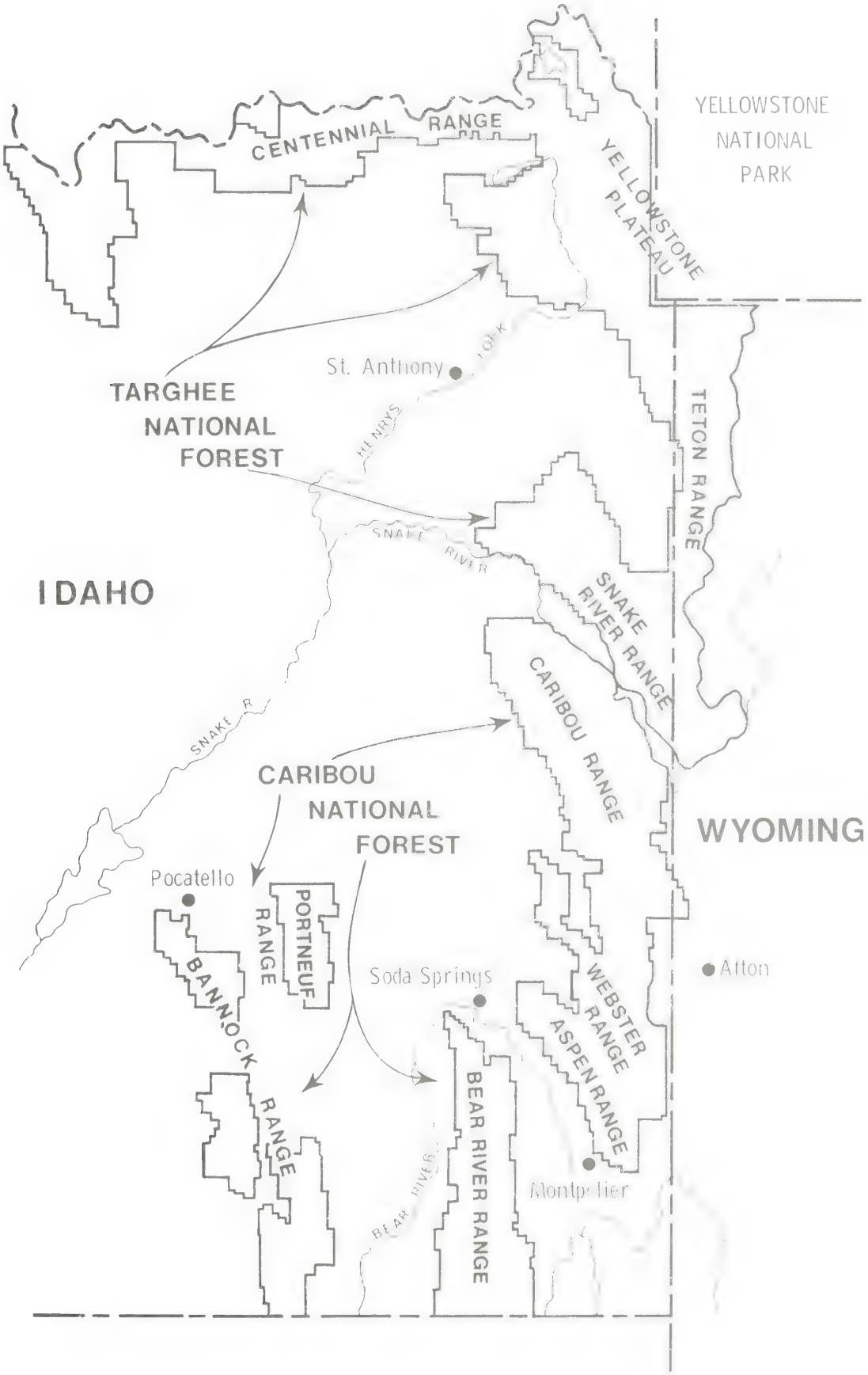

Figure 1.—The Targhee and Caribou National Forests in southeastern Idaho covered by this classification, including the locations of the main mountain ranges.

Data Analysis

Species composition data from the total 325 stands were used to develop the community type classification. Analyses of these data took two main forms.[1] First, similarity between stands was computed using species canopy cover and Sorensen's community coefficient (Gauch and Whittaker 1972, Mueller-Dombois and Ellenberg 1974). A minimum canopy cover value of 3 percent qualified a species for inclusion in comparisons; aspen was the only species arbitrarily excluded from the comparisons since its presence was a criterion for stand selection. The minimum value constraint was imposed to eliminate those species contributing very little to community composition. Similarity index values can range from 0.00 to 1.00, with the latter indicating identical species having identical canopy cover in compared stands. Of the 31,375 comparisons, only 8.9 percent had values exceeding 0.50 and only 1.5 percent had values exceeding 0.66. Cluster analyses of the similarity indices, using the unweighted-pair-group method with arithmetic averages (Sokal and Sneath 1964; Marshal and Romesburg 1977), permitted initial groupings which gave insights to community relationships. This objective, numerical taxonomic approach, however, did not by itself result in community groupings sensible for management. We believe that the relatively few species exerting a dominant role, as expressed by a combination of life form and amount of canopy cover, should be stressed in the development of a meaningful classification. The importance of these species appeared to be overshadowed by the great variation in presence and cover of relatively minor species in the computation of the similarity indices.

The second form of analysis, the synthesis or association table method (Mueller-Dombois and Ellenberg 1974), permitted subjective recognition of similarities in vegetational structure in species fidelity, constancy, and coverage. Numerous reiterations of stand alignments permitted sequencing the stands according to visual similarities of occurrence and structural dominance of what we consider important species indicative of environment, grazing degradation, and management concern.

The stands were subsequently grouped into community types according to the constancy and dominance of the selected indicator species. Vegetational structure was a prime consideration in forming the groups. The presence or absence of substantial amounts of conifers in the overstory, or potentially so as judged by regeneration, was the first separation element. The presence of conifers was considered highly relevant because of successional implications. Those stands containing substantial amounts of conifers were categorized as aspen-conifer cover types, which were then further partitioned into community types. Given sufficient time, all such mixed cover types will probably succeed to coniferous forest climax communities in the normal course of succession. The presence or absence of a tall shrub layer and of a low shrub layer were the second and third elements considered in grouping stands. These shrub layers not only tend to reflect environmental differences but are also highly relevant to management. The prevalent or indicator species in the herb layer was the fourth element. Thus, species prevalence within the tree, tall shrub, low shrub, and herb life form classes were used to delineate and characterize the aspen community types. The resulting community type nomenclature consists of binomial and trinomial names based upon the primary trees, shrubs, and herbs used in the separations.

Following the grouping of stands into community types, a dichotomous key was prepared based upon characterizing species and checked against all stands. This key will facilitate field identification of the community types. The key is usable with a knowledge of five trees, seven shrubs, four graminoids, and five forbs.

The constancy of occurrence of species in stands within a community type and its average canopy cover was computed for the more important species. These values are summarized in appendix A for ready comparison of species composition in the different community types.

The basal area and site index of *Populus tremuloides* are summarized by community types in appendix B. Eighty-year site index was computed for each of the intensively sampled stands using Jones' (1967) site index curves for aspen.

Undergrowth production, composition by vegetational classes, and forage suitability are summarized in appendix C. An approximation of suitability as livestock forage was derived from our species composition data based upon canopy cover, and from species palatability ratings developed for the Intermountain Region by USDA Forest Service (1969). The proportion of the summed canopy cover comprised of species falling into each of three desirability classes (desirable, intermediate, least) is considered an index to the value of the undergrowth as livestock forage.

Special Considerations

A word of explanation regarding our concept of plant community organization might add perspective to the development of the classification and its potential use. Seldom, if ever, do plant communities fall into clearcut taxonomic units. This is because no two plant communities are identical; species composition differs from place to place because of environmental and successional gradients as well as because of chance. Even where environmental stability and lack of physical disturbance have permitted the development of climax communities, subtle environmental differences from place to place and the factor of chance contribute to certain differences in the kinds and amounts of species comprising each community. Such differences in species composition are even more pronounced in seral vegetation which reflect in addition the variable effects of past and current disturbance. Vegetation classification, therefore, becomes a matter of arbitrarily deciding upon the amount of variability in composition tolerable in the taxonomic unit. This vegetation variability in turn reflects the amount of environmental and successional variability acceptable in defining the units. The amount of variability acceptable

[1]The assistance of R. L. Mauk, Utah State University, in the use of computer programs (MATRIX, ASSTAB, CONCOV) developed by him is gratefully acknowledged.

should be determined by the need for and projected use of the resulting classification.

Nomenclature of most plant species follows Hitchcock and others (1955-69), except in a few instances where Harrington (1954) is appropriate. Field identification of certain rather common species presented problems that were resolved by combining species. Positive separation of *Thalictrum occidentalis* and *Thalictrum fendleri* is very difficult without mature achenes; these two species are treated as *T. fendleri* since it is probably more common in the area. *Osmorhiza depauperata* and *Osmorhiza chilensis* are also difficult to separate without mature fruits and often occupy similar sites; they are combined as *O. chilensis*. Similarly, *Rosa nutkana* and *Rosa woodsii* are combined as *R. woodsii* since they are difficult to separate without flowers and apparently also hybridize. Field separation of *Arnica latifolia* and *Arnica cordifolia* can also be difficult at times; these two species are therefore combined as *A. cordifolia*, which tends to occupy the drier forested sites and was encountered most frequently. *Symphoricarpos albus* and *Symphoricarpos oreophilus* are difficult to separate unless one notes the small hollow hole in the pith of *S. albus* and the tendency of the nonrhizomatous *S. oreophilus* to occur in clumps. Steele and others (in press) indicate that *S. albus* tends to occupy terraces, moist areas, and fine textured soils, whereas *S. oreophilus* is more widespread and abundant on drier rocky sites. Youngblood and Mueggler (1981) observed that *S. albus* was confined to northwestern Wyoming whereas *S. oreophilus* occurred throughout western Wyoming. We observed that *S. albus* was fairly well confined to the northern portion of eastern Idaho where both species frequently occupied the same site. Valid taxonomic separation of *Geranium fremontii* is questionable. This confusion is reflected by different floras which seldom treat both species. In Utah and Colorado the pink flowered *Geranium* with a nonglandular base is commonly called *G. fremontii*, whereas in Idaho and western Wyoming it is referred to as *G. viscosissimum* var. *nervosum*. We have chosen to use the *G. viscosissimum* name for this uncertain complex.

Community type classifications are intrinsically weak in ability to communicate information on successional status. Such classifications are based on **existing** floristics, which may be appreciably altered from climax. Whether a named type is seral or stable can have pronounced management implications. We have attempted to clarify the successional status of our aspen community types by linking them to Steele and others' (in press) coniferous forest habitat type classification, where appropriate, and to other community types in our classifications. This was done primarily by comparing species composition and environments in the context of probable changes caused by disturbance. At best, the linkages are only suggestive and will require intensive separate study for confirmation of the successional relationships.

COMMUNITY TYPES

This classification partitions those forest communities on the Caribou and Targhee National Forests in which aspen comprises at least 50 percent of the tree canopy into four cover types based upon the dominant overstory trees. The cover types are then separated into a total of 23 community types based upon dominant species in the undergrowth.

Cover and Undergrowth Types

Stands containing at least 5 percent canopy cover of *Abies lasiocarpa*, alone or combined with *Picea engelmannii*, are considered to be in the *Populus tremuloides-Abies lasiocarpa* cover type. Lacking this amount of the more tolerant conifers but containing at least 10 percent canopy cover of *Pseudotsuga menziesii* qualified a stand for the *P. tremuloides-P. menziesii* cover type. Lacking the above-named conifers but containing at least 10 percent canopy cover of *Pinus contorta* qualified for inclusion in the *P. tremuloides-P. contorta* cover type. Stands containing lesser amounts of conifers were relegated to the *P. tremuloides* cover type. These minimal cover requirements for conifers were subjectively judged to approximate the level required for the species to validly indicate site differences, as well as being indicative of successional trends.

The *P. tremuloides* cover type is further subdivided into three undergrowth types based upon vegetational structure. Those community types possessing a distinct tall shrub component are placed in the tall shrub undergrowth type. Those without a pronounced tall shrub layer but that possess a distinct layer of low shrubs are placed in the low shrub undergrowth type. Community types that lack a well-defined layer of shrubs are placed within the herb undergrowth type.

Community types within a cover type were partitioned on the basis of dominant species composition within the shrub and herb layers. The community type name consists of the one or two characterizing tree species in the cover type, followed by the one or two characterizing shrub species (if present), which is then followed by the characterizing forb or grass. In no case does a name exceed a trinomial of the most characteristic species.

Only six community types were identified within cover types containing conifers. The remaining 17 community types are all contained within the *Populus tremuloides* cover type. Community type categories were based upon as few as two and as many as 53 stands. Forty percent of all stands sampled fell into the following three community types: *Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus* c.t.; *P. tremuloides/S. oreophilus-Calamagrostis rubescens* c.t.; *P. tremuloides/C. rubescens* c.t. A listing of all community types is given in table 1. Of the 325 stands sampled, only six could not be matched with any of the 23 community types listed.

Successional Status

The community types described by this study are classification units reflecting existing vegetation. We did not attempt to selectively sample only those communities thought to be in balance with their environment (climax communities). The community types thus represent both vegetation that is relatively stable with the environment as well as vegetation that is seral and changing to a type having considerably different composition.

Table 1.—*Aspen community types (c.t.) by cover type categories on the Caribou and Targhee National Forests*

Cover type and community type	Abbreviation
Populus tremuloides-Abies lasiocarpa cover type	
P. tremuloides-A. lasiocarpa/Symphoricarpos oreophilus c.t.	POTR-ABLA/SYOR
P. tremuloides-A. lasiocarpa/Thalictrum fendleri c.t.	POTR-ABLA/THFE
Populus tremuloides-Pseudotsuga menziesii cover type	
P. tremuloides-P. menziesii/Amelanchier alnifolia c.t.	POTR-PSME/AMAL
P. tremuloides-P. menziesii/Symphoricarpos oreophilus c.t.	POTR-PSME/SYOR
P. tremuloides-P. menziesii/Calamagrostis rubescens c.t.	POTR-PSME/CARU
Populus tremuloides-Pinus contorta cover type	
P. tremuloides-P. contorta/Calamagrostis rubescens c.t.	POTR-PICO/CARU
Populus tremuloides cover type	
(Tall Shrub undergrowth type)	
P. tremuloides/Amelanchier alnifolia-Pachistima myrsinites c.t.	POTR/AMAL-PAMY
P. tremuloides/Amelanchier alnifolia-Spiraea betulifolia c.t.	POTR/AMAL-SPBE
P. tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus c.t.	POTR/AMAL-SYOR
P. tremuloides/Amelanchier alnifolia-Calamagrostis rubescens c.t.	POTR/AMAL-CARU
(Low Shrub undergrowth type)	
P. tremuloides/Pachistima myrsinites-Calamagrostis rubescens c.t.	POTR/PAMY-CARU
P. tremuloides/Pachistima myrsinites-Geranium viscosissimum c.t.	POTR/PAMY-GEVI
P. tremuloides/Spiraea betulifolia-Calamagrostis rubescens c.t.	POTR/SPBE-CARU
P. tremuloides/Symphoricarpos oreophilus-Calamagrostis rubescens c.t.	POTR/SYOR-CARU
P. tremuloides/Symphoricarpos oreophilus-Poa pratensis c.t.	POTR/SYOR-POPR
P. tremuloides/Symphoricarpos oreophilus-Rudbeckia occidentalis c.t.	POTR/SYOR-RUOC
P. tremuloides/Artemisia tridentata-Festuca idahoensis c.t.	POTR/ARTR-FEID
(Herb undergrowth type)	
P. tremuloides/Geranium viscosissimum c.t.	POTR/GEVI
P. tremuloides/Wyethia amplexicaulis c.t.	POTR/WYAM
P. tremuloides/Calamagrostis rubescens c.t.	POTR/CARU
P. tremuloides/Calamagrostis rubescens-Poa pratensis c.t.	POTR/CARU-POPR
P. tremuloides/Poa pratensis c.t.	POTR/POPR
P. tremuloides/Rudbeckia occidentalis c.t.	POTR/RUOC

Whether a community is seral or stable can appreciably affect management decisions. It is important, therefore, to be able to judge the successional status of community types. Community stability is indicated when existing individuals are replaced by their own progeny without disturbance; thus the community is self-perpetuating. In seral communities, current populations of some species tend to be replaced by other species resulting in gradual changes in composition. Accurate determination of stability may require intensive ecological studies; however, initial judgments can be made by examining stand age structure, trends toward shade-tolerant species, and the relative abundance of species known to increase with such disturbances as abusive livestock grazing. Such indices permitted us to develop the probable successional status of each community type (table 2).

Twelve of the community types were thought to be stable and should probably be considered to represent aspen habitat types. Six others are considered seral within coniferous forest habitat types described by Steele and others (in press), and the remaining five are thought to be seral communities caused by abusive grazing in both aspen and coniferous forest habitat types. The relationship of a seral community type to a specific habitat type was judged by similarities in composition of the vegetation, by perceived alterations attributable to successionary trends, and by similarities in environment. The uncertainty of placement in a specific habitat type is caused primarily by the lack of clearly defined relationships. As Huschle and Hironaka (1980) have pointed out, however, all community types are not unique to a habitat type. It is therefore possible for a specific community type to be a seral type in more than one habitat type, or possibly seral on one site and stable on another.

Relation to Bridger-Teton Aspen Classification

A number of differences exist between the aspen community types described for the Bridger-Teton National Forest in western Wyoming (Youngblood and Mueggler 1981) and those described here for the Caribou and Targhee National Forests. These differences stem primarily from two separate causes: (1) actual vegetational differences attributable to differences in both environment and floristic geography; (2) differences in concepts used in developing the classifications regarding meaningful assemblages of species. Additionally, selection of nomenclature for similar community types has caused some minor discrepancies.

We did not encounter in southeastern Idaho 14 of the species assemblages described as community types for the Bridger-Teton National Forest (table 3). Most of the types not observed in Idaho only occurred infrequently in

Table 2.—*Probable relationships between aspen community types on the Caribou and Targhee National Forests and previously identified habitat types*

Aspen community type	Probable habitat type	Other possible habitat type
POTR-ABLA/SYOR	ABLA/CARU, CARU phase [1]	ABLA/OSCH [1]
POTR-ABLA/THFE	ABLA/OSCH, PAMY phase [1]	ABLA/THOC [1]
POTR-PSME/AMAL	PSME/SYAL [1]	PSME/OSCH [1] PSME/CARU [1]
POTR-PSME/SYOR	PSME/CARU [1]	PSME/OSCH [1] PSME/SYAL [1]
POTR-PSME/CARU	PSME/CARU [1]	(none)
POTR-PICO/CARU	ABLA/CARU [1]	PSME/CARU [1]
POTR/AMAL-PAMY	POTR/AMAL-PAMY [2]	ABLA/CARU, PAMY phase [1] PSME/CARU, PAMY phase [1]
POTR/AMAL-SPBE	POTR/AMAL-SPBE [2]	PSME/SPBE, CARU phase [1] PSME/SYAL [1]
POTR/AMAL-SYOR	POTR/AMAL-SYOR [2]	PSME/SYAL [1] ABLA/SYAL [1]
POTR/AMAL-CARU	POTR/AMAL-CARU [2]	PSME/CARU, CARU phase [1]
POTR/PAMY-CARU	POTR/PAMY-CARU [2]	PSME/CARU, PAMY phase [1] ABLA/CARU, PAMY phase [1]
POTR/PAMY-GEVI	POTR/PAMY-GEVI [2]	ABLA/OSCH, PAMY phase [1]
POTR/SPBE-CARU	POTR/SPBE-CARU [2]	PSME/SPBE, CARU phase [1] PSME/SYAL [1]
POTR/SYOR-CARU	POTR/SYOR-CARU [2]	PSME/CARU, CARU phase [1] ABLA/CARU, CARU phase [1]
POTR/SYOR-POPR	POTR/SYOR-CARU [2]	PSME/CARU, CARU phase [1] ABLA/CARU, CARU phase [1]
POTR/SYOR-RUOC	(uncertain)	ABLA/THOC [1]
POTR/ARTR-FEID	POTR/ARTR-FEID [2]	ARTR/FEID [3]
POTR/GEVI	POTR/GEVI [2]	ABLA/THOC [1]
POTR/WYAM	POTR/WYAM [2]	(none)
POTR/CARU	POTR/CARU [2]	PSME/CARU, CARU phase [1]
POTR/CARU-POPR	POTR/CARU [2]	PSME/CARU, CARU pl[illegible]
POTR/POPR	POTR/CARU [2]	ABLA/CARU, CARU pl[illegible] PSME/CARU, CARU phase [1]
POTR/RUOC	(uncertain)	ABLA/THOC [1]

[1] Habitat types in southeastern Idaho described by Steele and others (in press).
[2] Apparently stable aspen community types described in this study that should be recognized as distinct habitat types
[3] Hironaka and Fosberg (1979)

western Wyoming. The *Populus tremuloides/Ligusticum filicinum* and *P. tremuloides/Berberis repens* community types, however, were fairly common in western Wyoming yet were not recognized in southeastern Idaho. The abundance of *L. filicinum* in the former and *B. repens* in the latter are characteristic and distinct markers for these two types. Although both of these species occur in southeastern Idaho, they seldom if ever were observed in sufficient abundance to warrant community type designation based on their relative dominance.

In developing our classification we stressed separation of species assemblages based upon what we considered were the features potentially most relevant to management. Concepts of relevancy change, and hopefully mature, with increased knowledge of vegetation diversity and perceived management needs. Overall vegetation structure received foremost consideration. As with the Bridger-Teton classification, presence of critical amounts of conifers was a primary separation feature. In contrast to the Bridger-Teton classification, however, we used critical amounts of tall shrub synusia and a low shrub synusia as second and third elements in forming the Caribou and Targhee classification. The prevalent taxon,

Table 3.—*Community types described for the Bridger-Teton National Forest (Youngblood and Mueggler 1981) are different than, equivalent to, or contained within those indicated for the Caribou and Targhee National Forests*

Aspen Community types	
Bridger-Teton N.F.	**Caribou and Targhee N.F.'s**
POTR-ABLA/PRVI	different
POTR-ABLA/LIFI	different
POTR-ABLA/PERA	different
POTR-ABLA/BERE	different
POTR-ABLA/SHCA	different
POTR-ABLA/ARCO	different
POTR-ABLA/RUOC	different
POTR-PSME/SPBE	different
POTR/RAAL	different
POTR/EQAR	different
POTR/LIFI	different
POTR/JUCO	different
POTR/BERE	different
POTR/SHCA	different
POTR/ASMI	different
POTR-PSME/SPBE	POTR-PSME/PRVI
POTR-PSME/CARU.....	POTR-PSME/SYOR POTR-PSME/CARU
POTR/PRVI	POTR/AMAL-SYOR POTR/AMAL-CARU
POTR/SPBE	POTR/AMAL-SPBE POTR/SPBE-CARU
POTR/SYOR	POTR/SYOR-CARU POTR/SYOR-POPR POTR/PAMY-GEVI
POTR/ARTR	POTR/ARTR-FEID
POTR/CARU	POTR/SYOR-CARU POTR/CARU POTR/CARU-POPR
POTR/ARCO.....	POTR/GEVI different
POTR/THFE	POTR/GEVI different
POTR/HELA	POTR/RUOC
POTR/RUOC.....	POTR/RUOC
POTR/WYAM	POTR/WYAM

or taxa, in the herb layer was the final element considered. Thus, a prominent community type such as POTR/CARU in the Bridger-Teton classification will be found subdivided in the Caribou and Targhee classification (table 3), depending upon the presence of critical levels of *Symphoricarpos oreophilus*. Similarly, the POTR/SYOR community type of the Bridger-Teton classification has been subdivided, depending upon prevalent indicator species in the herb layer.

The matter of nomenclature preference is illustrated by the POTR/HELA type of the Bridger-Teton classification contained within the POTR/RUOC type of the Caribou and Targhee classification (table 3). POTR/HELA appear fairly distinct on the Bridger-Teton because of the constancy of *Heracleum lanatum*; however, *Rudbeckia occidentalis* not only was equally constant but usually had greater cover. The lesser constancy and cover of *H. lanatum* in what otherwise appears to be a fairly similar assemblage of species in southeastern Idaho prompted us to label this as a POTR/RUOC community type.

Vegetation Key

Table 4 consists of a vegetational key that permits identification of the aspen community types on the Caribou and Targhee National Forests. This key should be used with caution elsewhere because it has not been tested other than on these two forests. The key utilizes canopy cover estimates of common species within the tree, shrub, and herbaceous layers. The key was designed for use on those forest stands where *Populus tremuloides* comprises at least 50 percent of the tree canopy. Minimal canopy cover percentages of characterizing species are given only as approximate guides and should not be construed as absolute separation criteria. Difficulties encountered using the key and interpreting separation criteria can usually be resolved by comparing stand values with the constancy-cover summaries for each community type given in appendix A.

Each community type is briefly described in the order listed in table 1, which approximates the order presented in the key. These descriptions contain relevant information on distribution of the type, species composition and production, probable successional status, and whether similar communities have been reported elsewhere in the literature.

Table 4.—Vegetational key to aspen community types (c.t.) on the Caribou and Targhee National Forests, where *Populus tremuloides* comprises at least 50 percent of the tree canopy

Key To Cover Types:

I. *Abies lasiocarpa* or *Picea engelmannii* common, combined overstory and reproduction at least 5% canopy cover ..... *Populus tremuloides-Abies lasiocarpa* cover type (Go to A)

I. *A. lasiocarpa* and *P. engelmannii* absent, or less than 5% canopy cover II

II. *Pseudotsuga menziesii* common, combined overstory and reproduction at least 10% canopy cover ..... *Populus tremuloides-Pseudotsuga menziesii* cover type (Go to B)

II. *P. menziesii* absent, or less than 10% cover III

III. *Pinus contorta* common, at least 10% cover..... *Populus tremuloides-Pinus contorta* cover type (Go to C)

III. *P. contorta* less than 10% cover..... *Populus tremuloides* cover type (Go to D)

Key To Community Types:

A. *(Populus tremuloides-Abies lasiocarpa* cover type)

1. *Symphoricarpos albus* and/or *Symphoricarpos oreophilus* 10% or more canopy cover. . . *Populus tremuloides-Abies lasiocarpa/Symphoricarpos oreophilus* c.t. (p. 11)

1. *S. albus* and *S. oreophilus* less than 10% cover. 2

2. *Thalictrum fendleri* conspicuous; neither *Poa pratensis* nor *Rudbeckia occidentalis* abundant (less than 10% canopy cover) . . . . . *Populus tremuloides-Abies lasiocarpa/Thalictrum fendleri* c.t. (p. 11)

2. *P. pratensis* or *R. occidentalis* abundant 3

3. *Abies lasiocarpa* over 10% cover . . . . . (Undescribed community within this cover type)

3. *A. lasiocarpa* less than 10% canopy cover 4

4. *Poa pratensis* or *Poa nervosa* at least 20% cover . . . . . *Populus tremuloides/Poa pratensis* c.t. (p. 20)

4. *P. pratensis* or *P. nervosa* not abundant; *Rudbeckia occidentalis* cover 20% or greater . . . . . *Populus tremuloides/ Rudbeckia occidentalis* c.t. (p. 20)

B. *(Populus tremuloides-Pseudotsuga menziesii* cover type)

1. *Prunus virginiana* and/or *Amelanchier alnifolia* abundant, the combination usually at least 20% cover, if less, *Acer glabrum* prominent with more than 10% cover. . . . . *Populus tremuloides-Pseudotsuga menziesii/ Amelanchier alnifolia* c.t. (p. 11)

1. Combination of *P. virginiana*, *A. alnifolia* and *A. glabrum* less than 20% cover. 2

2. *Symphoricarpos albus* and/or *Symphoricarpos oreophilus* common, generally exceeding 10% canopy cover . . . . . *Populus tremuloides-Pseudotsuga menziesii/ Symphoricarpos oreophilus* c.t. (p. 12)

2. *S. albus* and *S. oreophilus* poorly represented, usually less than 5% cover 3

3. *Calamagrostis rubescens* abundant, generally exceeding 20% canopy cover . . . . . *Populus tremuloides Pseudotsuga men[illegible] Calamagrostis* [illegible] c.t. (p. 12)

3. Not as above . . . . . (Undescribed communities within this cover [illegible])

C. *(Populus tremuloides-Pinus contorta* cover type)

1. *Calamagrostis rubescens* conspicuous . . . . . *Populus tremuloides Pinus contorta/Calamagrostis rubescens* c.t. (p. 13)

1. *C. rubescens* absent. . . . . (Undescribed communities within this cover type)

D. *(Populus tremuloides* cover type)

1. *Amelanchier alnifolia* and *Prunus virginiana* absent or scarce (less than 5% cover) . 6

1. *A. alnifolia* and/or *P. virginiana* generally exceeding 10% canopy cover 2

2. *Pachistima myrsinites* generally exceeding 1[illegible] cover . . . . . *Populus tremuloides/ Amelanchier alnifolia-Pachistima myrsinites* c.t (p. 13)

2. *P. myrsinites* absent or scarce (less than 5% cover) 3

3. *Spiraea betulifolia* generally exceeding 10% canopy cover . . . . . *Populus tremuloides Amelanchier alnifolia Spiraea betulifo[illegible]* (p. 14)

3. *S. betulifolia* absent or scarce (less than 5% cover). 4

4. *Symphoricarpos oreophilus* and/or *Symphoricarpos albus* generally exceeding 10% cover. . . . . *Populus tremuloides/ Amelanchier alnifolia Symphoricarpos oreophilus* c.t. (p. 14)

4. *S. oreophilus* and *S. albus* poorly represented, less than 5% cover 5

5. *Calamagrostis rubescens* present . . . . . *Populus tremuloides Amelanchier alnifolia-[illegible]magrostis rube[illegible]* c.t. (p. 15)

5. *C. rubescens* absent. . . . . (Undescribed commu[illegible]

6. *Pachistima myrsinites* absent or scarce, less than 5% cover 8

6. *P. myrsinites* usually exceeding 10% canopy cover 7

Key To Community Types: (con.)

7. *Calamagrostis rubescens* abundant, generally exceeding 20% canopy cover ..... *Populus tremuloides/ Pachistima myrsinites-Calamagrostis rubescens* c.t. (p. 15)

7. *C. rubescens* poorly represented, less than 10% cover . *Populus tremuloides/ Pachistima myrsinites-Geranium viscosissimum* c.t. (p. 15)

8. *Spiraea betulifolia* abundant, generally exceeding 20% canopy cover; *Calamagrostis rubescens* prominent ..... *Populus tremuloides/ Spiraea betulifolia-Calamagrostis rubescens* c.t. (p. 16)

8. *S. betulifolia* absent or scarce, less than 5% cover 9

9. *Artemisia tridentata* and *Festuca idahoensis* at least 5% canopy cover each ..... *Populus tremuloides/ Artemisia tridentata-Festuca idahoensis* c.t. (p. 17)

9. *A. tridentata* and *F. idahoensis* absent or less than 5% cover 10

10. *Symphoricarpos oreophilus* and *Symphoricarpos albus* absent or scarce, less than 5% cover 14

10. *S. oreophilus* and/or *S. albus* generally exceeding 10% canopy cover 11

11. *Calamagrostis rubescens* and/or *Carex geyeri* at least 5% and usually more than 20% canopy cover ..... *Populus tremuloides/ Symphoricarpos oreophilus-Calamagrostis rubescens* c.t. (p. 16)

11. *C. rubescens* and *C. geyeri* absent or scarce, less than 5% cover 12

12. *Rudbeckia occidentalis* at least 5% canopy cover ... *Populus tremuloides/ Symphoricarpos oreophilus-Rudbeckia occidentalis* c.t. (p. 17)

12. *R. occidentalis* absent or scarce, less than 5% cover 13

13. *Poa pratensis* and/or *Poa nervosa* exceeding 10% cover ..... *Populus tremuloides/ Symphoricarpos oreophilus Poa pratensis* c.t. (p. 17)

13. *P. pratensis* and/or *P. nervosa* less than 10% cover..... (Undescribed communities)

14. *Wyethia amplexicaulis* abundant at least 20% canopy cover ..... *Populus tremuloides/ Wyethia amplexicaulis* c.t. (p. 18)

14. *W. amplexicaulis* absent or scarce..... 15

15. *Calamagrostis rubescens* and *Carex geyeri* absent or scarce..... 17

15. *C. rubescens* and/or *C. geyeri* abundant, more than 20% cover 16

16. *Poa pratensis* and/or *Poa nervosa* abundant, exceeding 20% cover..... *Populus tremuloides/ Calamagrostis rubescens-Poa pratensis* c.t. (p. 19)

16. *P. pratensis* and *P. nervosa* if present, not exceeding 10% cover ..... *Populus tremuloides/ Calamagrostis rubescens* c.t. (p. 19)

17. *Poa pratensis* and/or *Poa nervosa* abundant, often greatly exceeding 20% cover ..... *Populus tremuloides/Poa pratensis* c.t. (p. 20)

17. *P. pratensis* and *P. nervosa* absent or scarce, less than 5% cover 18

18. *Rudbeckia occidentalis* abundant, with 20% or greater canopy cover ..... *Populus tremuloides/ Rudbeckia occidentalis* c.t. (p. 20)

18. *R. occidentalis* absent or scarce..... 19

19. *Geranium viscosissimum* common. usually with 20% or greater cover ..... *Populus tremuloides/ Geranium viscosissimum* c.t. (p. 18)

19. Not as above ..... (Other undefined communit types)

TYPE DESCRIPTIONS

Populus tremuloides-Abies lasiocarpa/ Symphoricarpos oreophilus Community Type (POTR-ABLA/SYOR c.t.)

This relatively minor community type was encountered primarily on the Caribou National Forest, but also on the southern portion of the Targhee National Forest. Stands sampled in this type occurred on various aspects at elevations between 6,900 and 7,600 ft (2 100 and 2 320 m).

The conspicuous presence of *Abies lasiocarpa* in the overstory and as regeneration, along with an abundance of *Symphoricarpos* spp. in the undergrowth, characterize the type (fig. 2). Other species present and usually conspicuous are *Geranium viscosissimum*, *Lupinus argenteus*, and *Osmorhiza chilensis*. In some stands the herbaceous layer may be dominated by *Calamagrostis rubescens;* such stands might well be considered a separate community type. The POTR-ABLA/SYOR c.t. is most likely a seral community within the *A. lasiocarpa/ C. rubescens* habitat type described by Steele and others (in press) as occurring in southeastern Idaho. It might, however, also be a seral stage in the *A. lasiocarpa/ Osmorhiza chilensis* habitat type (Steele and others, in press).

Figure 2.—A *Populus tremuloides-Abies lasiocarpa/Symphoricarpos oreophilus* community type in the Bear River Range; this community typifies seral aspen gradually being replaced by *A. lasiocarpa* in the normal course of succession.

The basal area of *Populus tremuloides* on stands sampled within this type was relatively low, averaging 111 ft^2/acre (25.5 m^2/ha), but the site index was near the average of all types, 54 ft (16.5 m) at 80 years. Most *P. tremuloides* were less than 8 inches (20 cm) d.b.h., with only a few as large as 12 inches (30 cm). *P. tremuloides* was reproducing poorly in most cases.

Undergrowth production was characteristically low within the type, averaging less than 410 dry lb/acre (460 kg/ha). Two-thirds of this production consisted of forbs, and the remainder was divided about equally between shrubs and graminoids. Over half of the canopy cover consisted of species considered desirable as livestock forage.

Youngblood and Mueggler (1981) described a *P. tremuloides-A. lasiocarpa/Berberis repens* community type in western Wyoming which is somewhat similar to our POTR-ABLA/SYOR c.t., particularly with respect to the abundance of *S. oreophilus* in the undergrowth. Usually their type also contained abundant *B. repens* and *Pachistima myrsinites* which were rather sparse in our type.

Populus tremuloides-Abies lasiocarpa/ Thalictrum fendleri Community Type (POTR-ABLA/THFE c.t.)

The POTR-ABLA/THFE c.t. appears to be a minor type that was encountered only on the Bear River and Bannock Ranges of the Caribou National Forest. The three stands sampled occurred at relatively high elevations (between 6,500 and 8,200 ft [1 980 and 2 500 m]). The lower elevation stands occurred on northeasterly exposures whereas the upper stand occupied a southwest exposure.

The vegetation in this type is characterized by conspicuous amounts of *Abies lasiocarpa* associated with *Populus tremuloides*, both in the overstory and as regeneration, and an abundance of *Thalictrum fendleri* in the undergrowth. The type differs from the POTR-ABLA/ SYOR c.t. by the lesser amount of *Symphoricarpos* spp., which may be present but not exceeding 10 percent canopy cover. Other conspicuous species in the type usually include *Geranium viscosissimum*, *Osmorhiza chilensis*, and *Fragaria vesca*. The POTR-ABLA/THFE c.t. is a successional stage within the *A. lasiocarpa/ O. chilensis* habitat type (Steele and others, in press).

Neither the overstory nor undergrowth productivity was measured in this type. Slightly over half of the undergrowth canopy cover, however, consisted of species considered desirable as livestock forage.

The *P. tremuloides-A. lasiocarpa/Arnica cordifolia* community type described for western Wyoming (Youngblood and Mueggler 1981) is fairly similar to this type, except it contains considerably more *A. cordifolia* and *Poa nervosa* and less *Thalictrum fendleri* than our POTR-ABLA/THFE c.t.

Populus tremuloides-Pseudotsuga menziesii/Amelanchier alnifolia Community Type (POTR-PSME/AMAL c.t.)

This community type was found primarily along the Snake River and Teton Ranges, and on the Warm River portion of the Yellowstone Plateau. The stands sampled usually occurred on fairly steep slopes (average 32 percent) on southerly exposures, ranging in elevation from approximately 5,400 to 6,700 ft (1 650 to 2 050 m).

Pseudotsuga menziesii is the primary and usually the only conifer occurring within the type. *Prunus virginiana*, *Amelanchier alnifolia*, and *Acer glabrum*, either alone or

in combination, form a conspicuous tall shrub layer with a canopy cover frequently exceeding 25 percent. Lesser amounts of low shrubs such as *Symphoricarpos* spp., *Rosa woodsii*, and *Berberis repens* may also be present. The herbaceous layer is usually dominated by *Calamagrostis rubescens, Elymus glaucus*, and *Thalictrum fendleri*, often with appreciable amounts of *Osmorhiza chilensis, Geranium viscosissimum*, and *Aster engelmannii*. This is considered a successional stage within the *P. menziesii* conifer forest series. Judging from comparisons of species composition, it probably occurs within either the *P. menziesii/Symphoricarpos albus, P. menziesii/O. chilensis*, or *P. menziesii/C. rubescens* habitat types described by Steele and others (in press). The successional process leading to dominance by *P. menziesii* appears to be generally very slow.

P. tremuloides production appeared to be moderate in this type, with basal areas averaging 152 ft^2/acre (35 m^2/ha) and a site index at 80 years of 53 ft (16.2 m). The trees were less than 10 inches (25 cm) d.b.h., with the majority falling between 4 and 8 inches (10 and 20 cm) d.b.h. A low to moderate amount of *P. tremuloides* reproduction was present.

Production of undergrowth was moderate to high, average 1,079 dry lb/acre (1 210 kg/ha). Approximately one-third of this consisted of current-year's growth of shrubs, half forbs, the remainder graminoids. This undergrowth was considered moderately suitable as livestock forage, with 50 percent of the total canopy cover comprised of species in the desirable forage category.

Youngblood and Mueggler (1981) described a *P. tremuloides-P. menziesii/Spiraea betulifolia* community type for western Wyoming somewhat similar to this type. It, however, usually contained appreciably more *S. betulifolia* and less *T. fendleri* than our POTR-PSME/AMAL c.t.

Populus tremuloides-Pseudotsuga menziesii/Symphoricarpos oreophilus Community Type (POTR-PSME/SYOR c.t.)

The POTR-PSME/SYOR c.t. was encountered on the Bear River and Aspen Ranges on the Caribou National Forest as well as on the west face of the Teton Range on the Targhee National Forest. The sampled stands occurred primarily on northerly exposures at elevations between 6,200 and 7,500 ft (1 900 and 2 290 m). This type appears to occupy sites that generally are less steep (average of 15 percent) and more moist than those occupied by the POTR-PSME/AMAL c.t.

The type is characterized by the conspicuous presence of *Pseudotsuga menziesii* accompanying the *Populus tremuloides* (*Pinus contorta* may also be present), a well-defined low shrub layer consisting largely of *Symphoricarpos* spp., and the lack of a distinct layer of tall shrubs. *Calamagrostis rubescens, Thalictrum fendleri*, or both usually dominate the herbaceous layer. Other prominent species frequently present are *Elymus glaucus, Geranium viscosissimum, Lupinus argenteus*, and *Osmorhiza chilensis*. This type is primarily seral within the *P. menziesii* coniferous forest series; it is unclear at present whether it falls within the *P. menziesii/C. rubescens* or *P. menziesii/O. chilensis* habitat types (Steele and others, in press), or both. In some cases it appears that the successional sequence may be from *P. tremuloides* dominance, to *P. contorta*, and then to *P. menziesii* dominance, or even very slowly to dominance by *Abies lasiocarpa*.

Production of *P. tremuloides* on the sampled sites was moderately high, averaging over 161 ft^2/acre (37 m^2/ha) basal area, with a site index at 80 years of 55 ft (16.8 m). Trees over 12 inches (30 cm) d.b.h. were present, but most fell within the 6- to 10-inch (15- to 25-cm) range. Reproduction of *P. tremuloides* was generally low.

Undergrowth production was moderate (averaging slightly over 900 dry lb/acre [1 000 kg/ha]). Forbs and graminoids about equally formed the bulk of this, with shrubs averaging only 3 percent of the total. An average 54 percent of the undergrowth canopy cover consisted of desirable forage species.

A very similar *P. tremuloides-P. menziesii/C. rubescens* community type was described for western Wyoming (Youngblood and Mueggler 1981). The primary difference is that stands can be placed within our POTR-PSME/SYOR c.t. even though *C. rubescens* is sparse or lacking. Also, *S. oreophilus* dominates the low shrub layer in our type, but occasionally may be lacking in the western Wyoming type.

Populus tremuloides-Pseudotsuga menziesii/Calamagrostis rubescens Community Type (POTR-PSME/CARU c.t.)

This community type was seen only along the northern portion of the Targhee National Forest on the Centennial Range and the Yellowstone Plateau. The type occurred at moderate elevations between 6,200 and 6,900 ft (1 900 and 2 100 m), on rather gently sloping terrain, and was not confined by aspect.

The type is characterized by the obvious presence of *Pseudotsuga menziesii* associated with *Populus tremuloides* in the overstory. *Pinus contorta* may also be present. Pronounced tall shrub and low shrub layers are lacking. A few low shrubs such as *Symphoricarpos* spp. and *Berberis repens* may be present but do not form a conspicuous stratum. The undergrowth is usually dominated by *Calamagrostis rubescens* (fig. 3). Other species prominent in the type include *Thalictrum fendleri, Geranium viscosissimum, Arnica cordifolia*, and *Lupinus argenteus*. The POTR-PSME/CARU c.t. is considered a seral stage within the *P. menziesii* coniferous forest series, probably falling within the *P. menziesii/C. rubescens* habitat type described by Steele and others (in press).

Production was measured only on a single stand within the type. In this stand, *P. tremuloides* basal area and site index were moderately high, with some trees exceeding 10 inches (25 cm) d.b.h. Undergrowth production was low, less than 500 lb/acre (560 kg/ha), consisting of about one-third forbs and two-thirds graminoids. Sixty two percent of the undergrowth canopy cover, however, consisted of desirable forage species.

Figure 3.—This *Populus tremuloides-Pseudotsuga menziesii/Calamagrostis rubescens* community type in the Centennial Range has a predominantly grassy undergrowth.

Floristically, this type closely resembles the *Populus tremuloides-Pseudotsuga menziesii/Calamagrostis rubescens* community type described by Youngblood and Mueggler (1981) for western Wyoming.

Populus tremuloides-Pinus contorta/ Calamagrostis rubescens Community Type (POTR-PICO/CARU c.t.)

The POTR-PICO/CARU c.t. was encountered scattered from the Aspen Range on the Caribou National Forest northward to the Yellowstone Plateau. The stands that were sampled ranged in elevation from approximately 5,700 to 8,000 ft (1 740 to 2 450 m). The type appeared most often on southerly exposures of gentle to moderately steep slopes.

Pinus contorta is the only conifer that conspicuously shares the tree overstory with *Populus tremuloides*. *Amelanchier alnifolia* is the only tall shrub of any consequence, but it is seldom abundant. Various species of low shrubs, such as *Symphoricarpos* spp., *Pachistima myrsinites*, and *Rubus parviflorus* may occur occasionally in substantial amounts. *Calamagrostis rubescens* is always a dominant species in the undergrowth (fig. 4). Other herbs often conspicuous are *Thalictrum fendleri*, *Osmorhiza chilensis*, *Geranium viscosissimum*, *Lupinus argenteus*, and *Elymus glaucus*. The type is clearly seral. The successional sequence appears to be toward a *P. contorta/C. rubescens* community type which may then go eventually to either a *Pseudotsuga menziesii/C. rubescens* or possibly *Abies lasiocarpa/C. rubescens* climax (Steele and others, in press).

P. tremuloides production and site index were high on the single stand sampled for productivity in this type. Many of the trees exceeded 14 inches (35 cm) d.b.h. Undergrowth production was low, less than 710 lb/acre (800 kg/ha). However, 73 percent of the undergrowth canopy cover consisted of species rated desirable as livestock forage; three-fourths of this consisted of graminoids and the remainder was primarily forbs.

Figure 4.—The *Populus tremuloides-Pinus contorta/Calamagrostis rubescens* community type will gradually succeed to conifer-dominated communities with *C. rubescens* undergrowth, note the absence of shrubs.

Populus tremuloides/Amelanchier alnifolia-Pachistima myrsinites Community Type (POTR/AMAL-PAMY c.t.)

This is a fairly common community type found on areas extending from the Bear River Range on the Caribou National Forest northward to the Snake River Range on the Targhee National Forest. The type occurred at moderate elevations ranging from 5,700 to 7,500 ft (1 740 to 2 290 m), on all exposures, and on moderately steep slopes.

The tree layer consists almost exclusively of *P. tremuloides*, although occasionally widely scattered conifers may be present. The type is characterized by prominent tall shrub and low shrub layers. The tall shrubs consist primarily of *Amelanchier alnifolia* or *Prunus virginiana* (or both), whereas *Pachistima myrsinites* is the dominant low shrub. *Symphoricarpos* spp. may be present, but it is seldom as abundant as *P. myrsinites*. Other shrubs commonly found in the type are *Berberis repens* and *Rosa woodsii*. The most abundant herbs usually are *Calamagrostis rubescens*, *Lupinus argenteus*, *Thalictrum fendleri*, and *Osmorhiza chilensis*. Occasionally *Carex geyeri*, *Arnica cordifolia*, and *Geranium viscosissimum* are abundant. Generally the type appears to be stable; however, it might also be slowly successional to a POTR-PSME/AMAL c.t. which in turn might be within either the *P. myrsinites* phase of the *Pseudotsuga menziesii/C. rubescens* h.t., or perhaps the *Abies lasiocarpa/C. rubescens* h.t. (Steele and others, in press).

P. tremuloides production in the POTR/AMAL-PAMY c.t. was fairly low, with a basal area averaging only 123 ft^2/acre (28.2 m^2/ha), but the site index was mod[illegible] Most trees were less than 8 inches (20 cm) d.b.h. and reproduction was low to moderate.

Undergrowth production was also fairly low, averaging only about 850 lb/acre (950 kg/ha). This production consisted of 40 percent shrubs, 31 percent forbs, and 29 percent graminoids. An average 56 percent of the under growth canopy cover consisted of species rated [illegible] as livestock forage.

Populus tremuloides/Amelanchier alnifolia-Spiraea betulifolia Community Type (POTR/AMAL-SPBE c.t.)

This rather infrequent community type was encountered only on the Yellowstone Plateau, and on the Teton and Snake River Ranges, where it occurred at relatively low-to-moderate elevations between 5,500 and 6,600 ft (1 675 and 2 015 m). Most examples of the type were found on moderately steep southwesterly exposures.

The vegetation of this type is characterized by the scarcity of conifers, by a prominent tall shrub layer dominated by *Amelanchier alnifolia* or *Prunus virginiana* (or both), and a low shrub layer usually dominated by *Spiraea betulifolia*. In some stands, *Symphoricarpos* spp. may be codominant in the low shrub layer with *S. betulifolia*. *Rosa woodsii* is a constant low shrub, but it is seldom abundant. The herb layer is usually dominated by *Calamagrostis rubescens* and *Thalictrum fendleri*, with *Geranium viscosissimum* and *Lupinus argenteus* occasionally abundant. The POTR/AMAL-SPBE c.t. appears in most cases to be relatively stable, judging from the incidental presence of conifers. In some cases, however, the type might represent a seral stage on either the *Pseudotsuga menziesii/Symphoricarpos albus* or possibly the *P. menziesii/S. betulifolia* habitat types described by Steele and others (in press) for this area.

Basal area productivity of *Populus tremuloides* in these communities ranged from low to moderate, averaging only 128 ft^2/acre (29.4 m^2/ha); the average site index, however, rated fairly high (60 ft [18.3 m] at 80 years). Some of the trees exceeded 12 inches (30 cm) d.b.h., but most were less than 8 inches (20 cm) d.b.h. Reproduction of *P. tremuloides* was generally low.

Total production of undergrowth was moderate to high, averaging approximately 1,000 dry lb/acre (1 120 kg/ha). The proportion of shrubs, forbs, and graminoids comprising this total varied greatly between stands. Usually the shrubs produced more than either of the other two classes. The suitability of this undergrowth as livestock forage was low to moderate, with only 48 percent of the total canopy of the undergrowth consisting of species rated desirable.

The *P. tremuloides/S. betulifolia* community type described by Youngblood and Mueggler (1981) appears to be very similar to this type floristically.

Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus Community Type (POTR/AMAL-SYOR c.t.)

POTR/AMAL-SYOR is one of the most abundant aspen community types in southeastern Idaho. It was encountered more frequently than any other type. It is most abundant on the Caribou, Snake River, and Teton Ranges in the central portion of the study area. The type usually occurs at relatively low to moderate elevations between 5,200 and 7,300 ft (1 585 and 2 225 m). Although it was most frequently found on moderately steep (average 25 percent) southerly exposures, it does not appear to be restricted by either aspect or slope steepness.

Conifers seldom occur in this type, and never in abundance. The type is characterized by the presence of a tall shrub layer in which *Amelanchier alnifolia* or *Prunus virginiana* (or both) are prominent (fig. 5), and a low shrub layer dominated by *Symphoricarpos* spp. Neither *Pachistima myrsinites* nor *Spiraea betulifolia* contribute substantially to the low shrub layer. The herbaceous component of the vegetation is usually dominated by one or more of the following species: *Calamagrostis rubescens, Elymus glaucus, Lupinus argenteus, Thalictrum fendleri,* and *Geranium viscosissimum.* Where grazing has been particularly abusive, *Poa pratensis* and *Poa nervosa* often tend to become abundant.

Figure 5.—This *Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus* type exemplifies those aspen communities with undergrowth consisting of both tall shrub and low shrub layers as well as an herb layer. It was the most frequent aspen community encountered in southeastern Idaho.

The POTR/AMAL-SYOR c.t. is considered to be primarily a stable community. Occasional stands, however, may be slowly successional to the POTR-PSME/AMAL c.t., which is considered a seral community within the *Pseudotsuga menziesii/Symphoricarpos albus* or possibly the *Abies lasiocarpa/S. albus* habitat types described by Steele and others (in press).

Production of *Populus tremuloides* appears to be fairly low, with basal area averaging only 105 ft^2/acre (24.1 m^2/ha) and a site index averaging 49 feet (14.9 m) at 80 years. Trees exceeding 12 inches (30 cm) d.b.h. were occasionally present, but most were less than 8 inches (20 cm) d.b.h. Reproduction of *P. tremuloides* averaged low to moderate.

Undergrowth production is moderately high, averaging almost 980 lb/acre (1 100 kg/ha). Although considerable variation exists between stands within the type, generally the undergrowth production consists of approximately equal amounts of forbs and graminoids, with shrub production averaging less than 20 percent of the total. Suitability of this undergrowth as forage is relatively high, with 56 percent of the canopy cover consisting of species rated desirable.

Hoffman and Alexander (1980) described a *P. tremuloides/S. oreophilus* habitat type for northwestern Colorado that appears similar to this type except for the

abundance of *Lathyrus leucanthus* and *Vicia americana* in the Colorado type.

A *P. tremuloides/S. oreophilus* habitat type described by Lewis (1975) for northern Nevada appears fairly similar to our type in that it contains the tall shrub element and a low shrub element dominated by *S. oreophilus*. The northern Nevada type, however, apparently lacks some of the characteristic herbs such as *C. rubescens*, *E. glaucus*, and *L. argenteus*. The *P. tremuloides/P. virginiana* community type described by Youngblood and Mueggler (1981) appears very similar to our POTR/AMAL-SYOR c.t.

Populus tremuloides/Amelanchier alnifolia-Calamagrostis rubescens Community Type (POTR/AMAL-CARU c.t.)

This common community type is widely dispersed across both the Caribou and Targhee National Forests. It was encountered at low through moderate elevations between 5,500 and 7,300 ft (1 675 and 2 225 m). The type most commonly occupied slopes with southerly aspects.

The following characterize the type: the virtual absence of conifers; a pronounced layer of tall shrubs dominated by *Amelanchier alnifolia*, or *Prunus virginiana*, or both; the absence of a well-defined low shrub layer; and an herbaceous layer usually dominated by *Calamagrostis rubescens*. Species composition is very similar to that of the POTR/AMAL-SYOR c.t. except for the virtual absence of a low shrub layer dominated by *Symphoricarpos* spp. In both types *Thalictrum fendleri*, *Elymus glaucus*, *Lupinus argenteus*, and *Geranium viscosissimum* may be important in the undergrowth, and *Poa pratensis* or *Poa nervosa* (or both) may tend to increase appreciably with repeated heavy grazing. The POTR/AMAL-CARU c.t. appears to be successionally stable in most cases. Where seral, it probably is a successional community within the *Pseudotsuga menziesii/C. rubescens* habitat type (Steele and others, in press).

Basal area production of *Populus tremuloides* appears to be moderate, averaging 141 ft^2/acre (32.4 m^2/ha), but the site index was fairly low, averaging only 49 ft (14.9 m) at 80 years. Although some stems exceeded 10 inches (25 cm) d.b.h., most were less than 8 inches (20 cm) d.b.h. *P. tremuloides* reproduction generally was moderately high, with stems under 1 ft (3 dm) high averaging over 730/acre (1 800/ha) and those 1 to 4.5 ft (3 to 14 dm) high averaging over 1,335/acre (3 300/ha).

Production of undergrowth appears moderate to high. Undergrowth averaged 1,035 lb/acre (1 160 kg/ha), the bulk of which was roughly equally divided between the forb and graminoid vegetation classes. An average of only 7 percent of the undergrowth consisted of shrubs. Overall suitability of the undergrowth as livestock forage is moderate to high; 57 percent of the canopy cover was comprised of species rated desirable.

Except for appreciably lesser quantities of *S. oreophilus*, this type appears fairly similar to the western Wyoming *P. tremuloides/P. virginiana* community type (Youngblood and Mueggler 1981).

Populus tremuloides/Pachistima myrsinites-Calamagrostis rubescens Community Type (POTR/PAMY-CARU c.t.)

The POTR/PAMY-CARU c.t. appears to be a fairly restricted type found primarily on the Aspen Range, but was also observed as far north as the northern end of the Caribou Range. The type occurred at elevations ranging from approximately 6,100 to 8,000 ft (1 850 to 2 450 m), and occupied primarily northerly aspects and moderately steep slopes.

The vegetation is characterized by a lack of conifers in the overstory, the absence of a pronounced tall shrub layer, a low shrub layer usually dominated by *Pachistima myrsinites*, and an herb layer dominated by *Calamagrostis rubescens*. Other species that are usually present and may be abundant include *Symphoricarpos oreophilus*, *Lupinus argenteus*, and *Geranium viscosissimum*. The type is thought to be primarily stable.

Populus tremuloides production appears to be only moderate in the type. Basal area of sampled stands averaged 145 ft^2/acre (33.3 m^2/ha), but site index averaged only 50 ft (15.2 m) at 80 years. Some of the trees in the sample plots exceeded 12 inches (30 cm) d.b.h., but most were less than 8 inches (20 cm) d.b.h. Reproduction of *P. tremuloides*, however, was usually abundant.

Undergrowth production appears to be fairly low, averaging approximately 640 lb/acre (717 kg/ha) on the sample plots. About 20 percent of this production consisted of shrubs, and the remainder was about equally divided between the forb and graminoid classes. This undergrowth is considered moderately suitable as livestock forage; an average 56 percent of the canopy cover consisted of species rated desirable.

The *P. tremuloides/C. rubescens* community type described by Youngblood and Mueggler (1981) for western Wyoming appears to be a generalization which includes our POTR/PAMY-CARU, POTR/SYOR-CARU, and POTR/CARU community types. *Calamagrostis rubescens* is a dominant herb in all of these types.

Populus tremuloides/Pachistima myrsinites-Geranium viscosissimum Community Type (POTR/PAMY-GEVI c.t.)

The POTR/PAMY-GEVI c.t. is concentrated on the Aspen and Webster Ranges of the Caribou National Forest, although it has been observed as far north as the west slope of the Teton Range. It was found most frequently at the higher elevations, from 6,900 to 8,200 ft (2 100 to 2 500 m), and not restricted by exposure.

This type differs from the POTR/PAMY-CARU c.t. primarily by the absence or reduced abundance of *Calamagrostis rubescens* in the herb layer; *Geranium viscosissimum* is generally considerably more abundant (fig. 6). *Pachistima myrsinites* remains a dominant low shrub, but *Symphoricarpos* spp. may also be abundant. A well-defined tall shrub layer is lacking. This [illegible] thought to be relatively stable.

Figure 6.—A *Populus tremuloides/Pachistima myrsinites-Geranium viscosissimum* community type in the Webster Range. This is an example of an aspen community with just low shrubs and herbs forming the undergrowth.

Production data were acquired from only two stands within the type. The basal area and site index of *Populus tremuloides* in these stands were fairly low, averaging 129 ft^2/acre (29.6 m^2/ha) and 47 ft (14.3 m) at 80 years. Most trees were less than 8 inches (20 cm) d.b.h. Reproduction of *P. tremuloides* was scarce.

Production of undergrowth was very low, averaging slightly over 500 lb/acre (560 kg/ha). Most of this consisted of forbs (65 percent), with shrubs and graminoids about equally sharing the remainder. The undergrowth is considered moderately desirable livestock forage since 51 percent of the cover consisted of species rated desirable.

This type is probably contained within the *P. tremuloides/Symphoricarpos oreophilus* community type described by Youngblood and Mueggler (1981) for western Wyoming.

Populus tremuloides/Spiraea betulifolia-Calamagrostis rubescens Community Type (POTR/SPBE-CARU c.t.)

Only three examples of this minor community type were observed, and all were on the western portion of the Yellowstone Plateau. These stands occurred at elevations between 6,000 and 6,800 ft (1 830 and 2 075 m), and occupied moderately steep southerly exposures.

Conifers are only incidental in the type. A pronounced tall shrub layer is absent, although minor qualities of *Prunus virginiana* may be present. A low shrub layer dominated by *Spiraea betulifolia* and *Symphoricarpus albus*, and an herb layer containing an abundance of *Calamagrostis rubescens* and *Thalictrum fendleri* are characteristic. The type appears to be either stable or possibly slowly seral to the *Pseudotsuga menziesii/S. betulifolia* or *P. menziesii/S. albus* habitat types described by Steele and others (in press).

Only one stand was intensively sampled for production. Although the basal area of *Populus tremuloides* was relatively great in this stand, 160 ft^2/acre (36.7 m^2/ha), the site index was only 46 ft (14 m) at 80 years. Trees ranged in size up to 12 inches (30 cm) d.b.h., with the majority in the 6- to 8-inch (15- to 20-cm) size class. Undergrowth production was moderate at approximately 850 lb/acre (950 kg/ha). Of this, 25 percent consisted of shrubs, 35 percent forbs, and 40 percent graminoids. This undergrowth was considered moderately suitable as forage; 53 percent of the canopy cover consisted of desirable species.

The *P. tremuloides/S. betulifolia* community type described by Youngblood and Mueggler (1981) for western Wyoming is floristically similar to this type except for the greater abundance of *Amelanchier alnifolia*.

Populus tremuloides/Symphoricarpos oreophilus-Calamagrostis rubescens Community Type (POTR/SYOR-CARU c.t.)

This is a major community type (fig. 7) that ranges broadly throughout eastern Idaho. It was second in abundance only to the POTR/AMAL-SYOR c.t. This type occurred at low-to-moderate elevations between 5,700 and 7,500 ft (1 740 and 2 290 m), and most frequently on moderately steep southerly exposures.

Figure 7.—The *Populus tremuloides/Symphoricarpos oreophilus-Calamagrostis rubescens* community type is very common in southeastern Idaho; the undergrowth generally consists of a productive mixture of low shrubs and herbs.

Conifers are scarce to nonexistent in this type, and a pronounced tall shrub layer is lacking. A distinct low shrub layer dominated by *Symphoricarpos* spp. is present. Both *S. albus* and *S. oreophilus* occur in these communities either alone or in combination. The forb layer is usually dominated by *Calamagrostis rubescens* if this grass is scarce, *Carex geyeri* is abundant. Other herbaceous species likely to be prominent are *Geranium viscosissimum, Lupinus argenteus, Thalictrum fendleri,* and *Elymus glaucus*. Under prolonged heavy grazing, *Poa pratensis* and *Poa nervosa* are likely to become abundant. The POTR/SYOR-CARU c.t. is considered primarily stable. Some communities keying to this type, however, may eventually succeed to the POTR-PSME/SYOR c.t., which is probably a seral type within the *Pseudotsuga*

menziesii/Calamagrostis rubescens habitat type described by Steele and others (in press).

Basal area production of *Populus tremuloides* within this type ranged from 86 to 206 ft^2/acre (19.7 to 47.3 m^2/ha), and averaged a low to moderately productive 138 ft^2/acre (31.7 m^2/ha). Site index was also low to moderate, averaging 51 ft (15.5 m) at 80 years. Although trees in the 10- to 12-inch (25- to 30-cm) size class were not uncommon, most were less than 8 inches (20 cm) d.b.h. Reproduction of *P. tremuloides* averaged low to moderate.

Although undergrowth production within the type ranged from approximately 470 to 2,050 lb/acre (525 to 2 300 kg/ha), the average was fairly high, 1,138 lb/acre (1 276 kg/ha). On the average, only 6 percent of this consisted of shrubs, and the remainder was about equally divided between forbs and graminoids. This undergrowth appeared well suited for livestock since 60 percent of the canopy cover consisted of species classed as desirable.

The *P. tremuloides/C. rubescens* type described by Youngblood and Mueggler (1981) for western Wyoming appears to be a generalization that includes this type as well as our POTR/PAMY-CARU and POTR/CARU community types. In central Idaho, Schlatterer (1972) described a somewhat similar *P. tremuloides/S. oreophilus-Carex geyeri* community that differed primarily by the substitution of *C. geyeri* for *C. rubescens*, the lack of *E. glaucus*, and the presence of herbaceous species such as *Festuca idahoensis* not found in our type.

Populus tremuloides/Symphoricarpos oreophilus-Poa pratensis Community Type (POTR/SYOR-POPR c.t.)

This type is fairly abundant and widely distributed over both forests. The sampled stands ranged from fairly low to moderately high elevations, 5,200 and 7,500 ft (1 585 and 2 290 m), and occurred most frequently on rather gently sloped (average 13 percent) southerly exposures.

The POTR/SYOR-POPR c.t. appears to be a distinct grazing disclimax of the POTR/SYOR-CARU c.t. It is characterized by the lack of conifers as a prominent part of the overstory, the absence of a distinct tall shrub layer, a low shrub layer dominated by *Symphoricarpos* spp., and the abundance of *Poa pratensis* and/or *Poa nervosa* and lack of *Rudbeckia occidentalis* in the herb layer. Other herbs frequently abundant include *Geranium viscosissimum, Lupinus argenteus, Bromus carinatus*, and *Taraxacum officinale*. The latter is additional evidence of a grazing disclimax.

Basal area production of *Populus tremuloides* appears moderate to high, ranging from 112 to 187 ft^2/acre (25.7 to 42.9 m^2/ha) in the sampled stands and averaging 154 ft^2/acre (35.4 m^2/ha). Site index is also fairly high, averaging 56 ft (17.1 m) at 80 years. Most of the trees were less than 8 inches (20 cm) d.b.h., although occasional trees up to 14 inches (35 cm) d.b.h. were encountered on the sample plots. Reproduction of *P. tremuloides* was fairly scarce.

Production of undergrowth appears moderate, averaging 914 lb/acre (1 025 kg/ha) in the sampled stands. Only 5 percent of this consisted of shrubs, 45 percent forbs, and 50 percent graminoids. Undergrowth provides poor livestock forage; only 41 percent of the undergrowth canopy cover consisted of desirable vegetation.

Populus tremuloides/Symphoricarpos oreophilus-Rudbeckia occidentalis Community Type (POTR/SYOR-RUOC c.t.)

This community type is widely distributed across the Caribou National Forest and southern end of the Targhee National Forest at moderate elevations, ranging from 5,700 to 7,200 ft (1 740 to 2 195 m), encountered most frequently on gentle to moderately steep south-facing slopes.

The POTR/SYOR-RUOC c.t. is a grazing disclimax characterized by a scarcity of conifers, lack of a distinct tall shrub layer, a low shrub layer dominated by *Symphoricarpos* spp., and the prominence of *Rudbeckia occidentalis* in the herb layer. *Elymus glaucus, Senecio serra*, and annuals are likely to be more prominent here than in the POTR/SYOR-POPR c.t., another grazing disclimax. Such annuals as *Nemophila breviflora* and *Collinsia parviflora* are often abundant. The type is probably a grazing disclimax of the POTR-ABLA/THFE c.t., but might also be seral to the POTR-ABLA/SYOR c.t. or POTR-PSME/SYOR c.t.

The type appears moderately productive for *Populus tremuloides*, averaging 139 ft^2/acre (31.9 m^2/ha) basal area, with a site index of 55 ft (16.8 m) at 80 years. Trees over 12 inches (30 cm) d.b.h. were not uncommon. *Populus tremuloides* reproduction was low.

The undergrowth appears very productive, averaging 1,248 lb/acre (1 399 kg/ha). Over 70 percent of this was forbs consisting primarily of *R. occidentalis*, 21 percent graminoids, and the remainder shrubs. Suitability of this undergrowth as livestock forage, however, was poor; only 30 percent of the total canopy cover consisted of species considered desirable and 32 percent least desirable.

Youngblood and Mueggler (1981) described a *P. tremuloides/R. occidentalis* community type for western Wyoming that is similar to this type except for the amount of *S. oreophilus*.

Populus tremuloides/Artemisia tridentata-Festuca idahoensis Community Type (POTR/ARTR-FEID c.t.)

The POTR/ARTR-FEID c.t. was found primarily at the lower elevations where the aspen zone merges into the sagebrush steppe. It is a minor type that was encountered most frequently along the gently sloping foothills and benches of the Centennial Range fringing the northern edge of the Upper Snake River Plains.

The type is characterized by the absence of both conifers and a tall shrub layer, and the prominence of *Artemisia tridentata* ssp. *vaseyana* in the low shrub layer and *Festuca idahoensis* in the herb layer. It appears to occupy a very restricted environment in an area where growth of *Populus tremuloides* is limited by moisture availability. The type usually occurs as peninsulas or small, single-clone islands in shrub steppes dominated by an *A. tridentata* and *Purshia tridentata* shrub layer.

with *F. idahoensis* the predominant herb. The type appears to be relatively stable. In some places, however, the tree overstory is not reproducing and succession appears to be leading to a shrub-steppe type dominated by *A. tridentata* and *F. idahoensis* similar to the *A. tridentata* ssp. *vaseyana/F. idahoensis* habitat type described by Hironaka and Fosberg (1979). Production was not measured in this type. Undergrowth production, however, is estimated to be low, between 550 and 800 lb/acre (600 and 900 kg/ha) of material only moderately suitable as livestock forage.

The type includes what appears to be a variant dominated by pigmy *P. tremuloides*. This variant occurs as small, isolated, single-clone groves surrounded by sagebrush steppe. The rather dense *P. tremuloides* overstory may be over 25 years old, but the basal diameters of the stems are only 2 to 3 inches (5 to 8 cm) and their heights seldom exceed 10 ft (3 m). Judging from the presence of old dead stems and the lack of evidence of fire, these groves apparently continue to reproduce naturally and persist for long periods of time. Whether the dwarf nature of the *P. tremuloides* in these clones is genetically or environmentally induced has not yet been determined. The environment is generally harsh. Some of these pigmy stands have crooked boles, which may be caused by drifting snow.

Youngblood and Mueggler (1981) described for western Wyoming a *P. tremuloides/A. tridentata* community type very similar to the POTR/ARTR-FEID c.t.

Populus tremuloides/Geranium viscosissimum Community Type

(POTR/GEVI c.t.)

This is a minor community type, unrestricted geographically, occurring at moderate to high elevations between 6,300 and 8,200 ft (1 920 and 2 500 m). It was encountered on moderately steep slopes and was not limited by exposure.

The type lacks appreciable amounts of conifers and well-defined shrub layers. Up to 10 percent canopy cover of *Symphoricarpos* spp. may be present, however. The herb layer is comprised primarily of forbs among which *Geranium viscosissimum* is always prominent. *Osmorhiza chilensis, Thalictrum fendleri, Lupinus argenteus,* and *Elymus glaucus* may also be abundant. Although *Rudbeckia occidentalis, Poa pratensis,* or *Poa nervosa* may be present, none of these contribute substantially to the undergrowth cover. The type is thought to be either stable or slowly successional to the POTR-ABLA/THFE c.t.

Only one stand was intensively sampled for productivity in this type. *Populus tremuloides* production was moderate to high, with 164 ft^2/acre (37.7 m^2/ha) basal area and a site index of 52 ft (15.8 m) at 80 years. Trees over 12 inches (30 cm) d.b.h. were fairly common in this stand. The undergrowth was only moderately productive at approximately 800 lb/acre (897 kg/ha). This consisted of 74 percent forbs and 25 percent graminoids. Forage suitability was fairly low, with only 47 percent of the canopy cover comprised of species rated desirable.

Youngblood and Mueggler (1981) described a *P. tremuloides/T. fendleri* community type for western Wyoming which is similar to this type except lacks the abundance of *Geranium viscosissimum* and *O. chilensis*. A somewhat similar *P. tremuloides/T. fendleri* habitat type occurs in northwestern Colorado (Hoffman and Alexander 1980); this type, however, contains substantial amounts of *Lathyrus leucanthus, Vicia americana,* and *Ligusticum porteri.*

Populus tremuloides/Wyethia amplexicaulis Community Type

(POTR/WYAM c.t.)

The POTR/WYAM c.t., although not abundant, is widely distributed from the Bear River Range in the south, northward to the Centennial Range. It was encountered at moderate elevations between 6,300 and 6,700 ft (1 920 and 2 050 m), usually on gently sloping terrain with fairly heavy soils.

The type is characterized by the lack of both conifers and well-defined shrub layers, and the dominance of *Wyethia amplexicaulis* in the undergrowth (fig. 8). Other species sometimes found in abundance include *Geranium viscosissimum, Poa pratensis, Rudbeckia occidentalis, Taraxacum officinale,* and *Elymus glaucus*. The type is considered fairly stable, but some stands appear to have been altered appreciably by heavy grazing. The overwhelming dominance of *W. amplexicaulis* and the abundance of *P. pratensis, R. occidentalis,* and *T. officinale* lend credence to rather severe grazing-induced changes.

Figure 8.—The distinctive *Populus tremuloides/Wyethia amplexifolius* community type usually occurs on gentle slopes or flats with fairly heavy soils. A dense undergrowth of *W. amplexifolius* may be at least partly attributed to abusive grazing in the past.

Populus tremuloides occurs in rather open, parklike stands in this type. The type appears to be the least productive for *P. tremuloides* of any of the community types observed, averaging only 74 ft^2/acre (17 m^2/ha) of basal area and a site index at 80 years of only 31 ft (9.4 m). Seldom did stems exceed 8 inches (20 cm) d.b.h., and reproduction was poor.

Undergrowth production appears to be high. The intensively sampled stands averaged 1,169 lb/acre (1 310 kg/ha) of undergrowth consisting of 90 percent forbs and 9 percent graminoids. This undergrowth, however, was among the least suitable for forage of any of the community types. Only 30 percent of the canopy cover consisted of species rated desirable, and 37 percent consisted of species rated least desirable for livestock forage.

A *P. tremuloides/W. amplexicaulis* community type was described by Youngblood and Mueggler (1981) for western Wyoming.

Populus tremuloides/Calamagrostis rubescens Community Type (POTR/CARU c.t.)

The POTR/CARU c.t. is the third most frequently encountered aspen community type in southeastern Idaho. It is widely distributed across both the Caribou and Targhee National Forests. The type has a wide elevational range, between 5,600 and 8,200 ft (1 700 and 2 500 m), and does not appear to be restricted by either exposure or slope gradient.

Conifers are usually incidental in this type; although *Pseudotsuga menziesii* may occasionally be present, by definition it never exceeds 10 percent canopy cover. Distinct tall shrub and low shrub layers are lacking; *Symphoricarpos oreophilus* is usually present, but only in small amounts. The undergrowth is principally herbaceous and dominated by *Calamagrostis rubescens* (fig. 9). Other prominent herbs usually include *Lupinus argenteus, Geranium viscosissimum, Osmorhiza chilensis, Thalictrum fendleri*, and occasionally *Elymus glaucus*.

Figure 9.—The undergrowth in the *Populus tremuloides/Calamagrostis rubescens* community type characteristically contains few shrubs but a luxuriant mixture of herbs dominated by *C. rubescens*.

The POTR/CARU c.t. is considered primarily a stable aspen type. Except for the difference in amounts of *Symphoricarpos* spp., it is quite similar to the POTR/SYOR-CARU c.t. Some communities, therefore, may be successional to the POTR/SYOR-CARU c.t., which in turn could eventually succeed to the POTR-PSME/SYOR c.t. which is a seral type probably within the *P. menziesii/C. rubescens* habitat type described by Steele and others (in press).

Production of *Populus tremuloides* appears to be moderate within this type; basal area of sampled stands averaged 144 ft^2/acre (33.1 m^2/ha), with a site index at 80 years of 54 ft (16.4 m). Occasional stems exceeded 12 inches (30 cm) d.b.h., but the majority were less than 8 inches (20 cm) d.b.h.. Reproduction of *P. tremuloides* was relatively great, with an average of 1,100 suckers/acre (2 700/ha) less than 1 ft (3 dm) high and over 1,500 suckers/acre (3 700/ha) between 1 and 4½ ft (3 and 14 dm) high.

Undergrowth production varied appreciably, between 469 and 1,270 lb/acre (526 and 1 424 kg/ha), and averaged a moderate 867 lb/acre (972 kg/ha); 65 percent of this consisted of graminoids, primarily *C. rubescens*, 33 percent forbs, and the remaining 2 percent shrubs. This undergrowth is generally suitable as livestock forage. An average 70 percent of the canopy cover consisted of species rated desirable while the remainder were rated moderately desirable forage species.

Opinions differ regarding the value of *C. rubescens* as a livestock forage, perhaps because palatability varies during the year. Although it is generally rated as fair to good forage for cattle in the Blue Mountains of eastern Oregon, Skovlin (1967) found that palatability and forage quality decline rapidly as the season advances. He determined that the crude protein content of *C. rubescens* was greater than that of other major forage species during July, but fell rapidly and was less than the other species by early September. McLean and others (1969) found that *C. rubescens* on the southern British Columbia rangelands contained adequate nutrients for rapid growth of yearlings until the first of August and for pregnant cows and replacement heifers until the first of September. It was readily eaten by cattle in British Columbia during early summer but became unpalatable by mid-August. Generally, it is not readily eaten by sheep.

A *P. tremuloides/C. rubescens* community type was also described by Youngblood and Mueggler (1981) for western Wyoming. Their type, however, contains considerable floristic variation which is separated by our POTR/PAMY-CARU and POTR/SYOR-CARU types.

Populus tremuloides/Calamagrostis rubescens-Poa pratensis Community Type (POTR/CARU-POPR c.t.)

Although most of the stands within this type were encountered on the Centennial Range at the northern end of the Targhee National Forest, a few stands were found as far south as the Caribou Range. Stands within this type occurred at moderate elevations, between 6,100 and 6,900 ft (1 850 and 2 100 m), on rather gentle slopes, and on all exposures.

The type appears to be a grazing-induced alteration of the POTR/CARU c.t. Conifers are only incidental, if present at all, and well-defined shrub layers are lacking. The undergrowth is dominated by *Calamagrostis rubescens* and either *Poa pratensis* or *Poa nervosa*. Although *C. rubescens* grows as a spreading mat, the shallow rootstalks of new plants apparently are easily

Figure 10.—The *Populus tremuloides/Poa pratensis* community type is considered a grazing disclimax where heavy grazing has permitted *P. pratensis* to invade and dominate the undergrowth.

pulled up with early grazing (Skovlin 1967). The type is differentiated from the POTR/CARU c.t. primarily by the great amount of *Poa* spp. A scattering of other graminoids and forbs may be present also, but *Geranium viscosissimum, Lupinus argenteus*, and *Taraxacum officinale* are usually the only ones that occur in any abundance.

Productivity of *Populus tremuloides* appears to be low to moderate, with an average basal area of 149 ft^2/acre (34.2 m^2/ha) and a site index of 47 ft (14.3 m) at 80 years. Stems over 14 inches (35 cm) d.b.h. were not uncommon, but most were less than 8 inches (20 cm) d.b.h. Sucker reproduction was relatively great.

Undergrowth productivity in the sampled stands was low to moderate, averaging 768 lb/acre (861 kg/ha). Graminoids comprised 56 percent of the total, forbs 42 percent, and the remainder was shrubs. This undergrowth is considered only moderately suitable as livestock forage; only 55 percent of the canopy cover consisted of species rated desirable.

Populus tremuloides/Poa pratensis Community Type (POTR/POPR c.t.)

This type is widely distributed throughout the Caribou and Targhee National Forests. It was encountered over a wide range in elevation, from 6,000 to 7,500 ft (1 830 to 2 290 m), on fairly gentle slopes and on all exposures. The type occurs primarily near stream and valley bottoms where livestock naturally tend to congregate.

The POTR/POPR c.t. is a grazing disclimax apparently caused by continuous heavy cattle use (fig. 10). It appears to be a further degradation of the POTR/SYOR-POPR c.t. The type is characterized by a lack of both conifers and well-defined shrub layers, and the almost exclusive dominance of *Poa pratensis* or *Poa nervosa* (or both) in the undergrowth. Other species that may be fairly abundant include *Taraxacum officinale, Lupinus argenteus, Geranium viscosissimum*, and *Thalictrum fendleri*.

Populus tremuloides productivity is usually very high, probably because of the relatively deep soils of the bottom lands where the type tends to occur. Its basal area averaged 220 ft^2/acre (50.5 m^2/ha), with a site index of 62 ft (18.9 m) at 80 years. Most stems were in the 8- to 12-inch (20- to 30-cm) d.b.h. size class; stems exceeding 14 inches (35 cm) d.b.h. were not uncommon. Sucker reproduction was low, possibly because of repeated heavy browsing.

Undergrowth production was only moderate, averaging 859 lb/acre (963 kg/ha). Of this, 61 percent was graminoids and 38 percent was forbs. The undergrowth was considered of low forage suitability, for only 33 percent of the canopy cover consisted of desirable forage species.

Populus tremuloides/Rudbeckia occidentalis Community Type (POTR/RUOC c.t.)

This minor type was observed only on the Webster, Aspen, and Bear River Ranges of the Caribou National Forest. It occurred at moderate elevations between 6,500 and 7,300 ft (1 980 and 2 225 m). Most stands were found on moderately steep southerly exposures.

Although the type lacks well-defined shrub layers, *Symphoricarpos* spp. is a constant shrub that occurs in only small quantities. *Abies lasiocarpa* is usually present as reproduction, but is never abundant. The type is characterized by the dominance of *Rudbeckia occidentalis* in the undergrowth. Other prominent species may include *Ligusticum filicinum, Agastache urticifolia, Osmorhiza occidentalis, Thalictrum fendleri, Heracleum lanatum, Fragaria vesca*, and *Elymus glaucus*. The type is thought to be a grazing modification of the POTR-ABLA/SYOR c.t

Productivity of *Populus tremuloides* in the type is rather low, averaging only 106 ft^2/acre (24.3 m^2/ha) basal area with a site index of 54 ft (16.5 m) at 80 years. Stems did not exceed 12 inches (30 cm) d.b.h.; most were less than 8 inches (20 cm) d.b.h. Sucker reproduction was relatively sparse. Undergrowth productivity was low to moderate, averaging approximately 794 lb/acre (890 kg/ha). Most of this undergrowth consisted of forbs, 81 percent; only 17 percent was graminoids. Forage suitability was fairly low; only 48 percent of the canopy cove consisted of desirable species and 17 percent consisted of least desirable species.

Our POTR/RUOC c.t. appears to be a composite of the *Populus tremuloides/Rudbeckia occidentalis* and *P. tremuloides/Heracleum lanatum* types described by Youngblood and Mueggler (1981).

Other Aspen Communities

Of the total 325 aspen stands examined in southeastern Idaho, only six did not fit the classification we developed. These stands were single encounters representing rather unusual situations. If encountered repeatedly, justification would exist for recognizing them as distinct community types.

Where aspen occupy a wet meadow, seep, or other high water-table site, the understory may be dominated by species especially well adapted to moist situations. Two such sites were observed in the Centennial Range. One semiwet meadow occuped by aspen had 75 percent canopy cover of *Alopecurus alpinus* and minor amounts of *Aster foliaceus* and *Elymus glaucus* in the undergrowth. In another, the undergrowth was dominated by *Agrostis alba* accompanied by *Aster foliaceus*, *Poa palustris*, *Geranium viscosissimum*, and *Taraxicum officinale*. One stand in the Portneuf Range on the Caribou National Forest was observed where *Carex aquatilis* completely dominated the undergrowth.

Near the Utah border in the Bear River Range a stand was encountered that had the undergrowth dominated by *Lathyrus lanszwertii*, with *E. glaucus* and *Nemophila breviflora* also abundant. Although this was the only such stand seen in southeastern Idaho, it appears very similar to some aspen communities observed in northern Utah. The abundance of *L. lanszwertii* may in part be attributable to heavy past grazing.

In one atypical situation with considerable ground disturbance by pocket gophers, *Linaria vulgaris* and *Nemophila breviflora* completely dominated the undergrowth. The stand occupied a gentle southwesterly exposure on the Yellowstone Plateau. Presumably, *L. vulgaris* invaded the site following severe soil disturbance.

One stand was observed on the Bear River Range where *Vaccinium globulare* completely dominated the undergrowth, with 70 percent canopy cover. This community occurred at 7,700 ft (2 350 m) elevation and had an overstory where *Populus tremuloides* and *Pinus contorta* were codominants, with lesser amounts of *Abies lasiocarpa*. The community was obviously seral within the *A. lasiocarpa/V. globulare* habitat type described by Steele and others (in press) for the area.

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APPENDIX A1

Appendix A1. Constancy and average canopy cover (latter in parenthesis) of important plants in aspen community types within the Caribou and Targhee National Forests. (Code for constancy values is at the bottom of the table; canopy cover is the average percent for those stands in which the species was found, except "**" denotes a trace value.)

Community Type:	POTR-ABLA/SYOR	POTR-ABLA/THFE	POTR-PSME/AMAL	POTR-PSME/SYOR	POTR-PSME/CARU	POTR-PICO/CARU	POTR/AMAL-PAMY	POTR/AMAL-SPBE	POTR/AMAL-SYOR	POTR/AMAL-CARU	POTR/PAMY-CARU	POTR/PAMY-[illegible]
No. of stands:	6	[illegible]	[illegible]	8	[illegible]	10	[illegible]	[illegible]	53	20	7	17
TREES												
Abies lasiocarpa > 1.5 m tall	8(9)	10(17)	1(**)	4(4)	–(0)	3(**)	2(1)	1(4)	[illegible]	[illegible]	–(0)	2(1)
Abies lasiocarpa < 1.5 m tall	10(4)	10(7)	–(0)	4(1)	[illegible]	2(2)	3(**)	[illegible]	[illegible]	[illegible]	[illegible]	4(**)
Juniperus scopulorum > 1.5 m	(0)	–(0)	–(0)	(0)	–([illegible]	–(0)	–(0)	–(0)	[illegible]	[illegible]	–(0)	–(0)
Juniperus scopulorum < 1.5 m	(0)	(0)	–(0)	(0)	[illegible]	–(0)	–(0)	1(**)	[illegible]	[illegible]	–(0)	–(0)
Picea engelmannii > 1.5 m	[illegible]	3(10)	–(0)	(0)	–(0)	–(0)	–(0)	–(0)	[illegible]	[illegible]	–(0)	–(0)
Picea engelmannii < 1.5 m	(0)	–(0)	–(0)	(0)	1(**)	[illegible]	–(0)	–(0)	[illegible]	[illegible]	[illegible]	–(0)
Pinus contorta > 1.5 m	3(13)	3(**)	[illegible]	4(12)	6(13)	10(22)	[illegible]	–(0)	2(4)	[illegible]	3(2)	4(2)
Pinus contorta < 1.5 m	3(**)	(0)	[illegible]	[illegible]	3(**)	7(1)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4(**)
Populus tremuloides > 1.5 m	10(62)	10(55)	10(57)	10(56)	10(52)	10(51)	10(72)	10(80)	10(71)	10(73)	10(77)	10(66)
Populus tremuloides < 1.5 m	8(3)	10(4)	8(2)	[illegible]	10(15)	7(8)	9(4)	10(4)	9(5)	[illegible]	10(12)	10(7)
Pseudotsuga menziesii > 1.5 m	2(15)	3(10)	10(24)	10(16)	10(17)	1(**)	[illegible]	8(2)	2(2)	[illegible]	3(3)	4(1)
Pseudotsuga menziesii < 1.5 m	5(2)	3(**)	[illegible]	[illegible]	4(**)	[illegible]	3(**)	3(**)	[illegible]	[illegible]	4(**)	2(**)
SHRUBS												
Acer glabrum	[illegible]	(0)	1(15)	(0)	–(0)	–(0)	–(0)	–(0)	+(1)	[illegible]	[illegible]	[illegible]
Acer grandidentatum	(0)	–(0)	1(**)	[illegible]	[illegible]	–(0)	3(6)	1(3)	1(5)	[illegible]	[illegible]	[illegible]
Amelanchier alnifolia	2(**)	7(1)	8(20)	6(3)	[illegible]	6(6)	10(24)	10(12)	9(22)	[illegible]	[illegible]	7(3)
Artemisia tridentata	[illegible]	[illegible]	–(0)	(0)	–(0)	–(0)	–(0)	–(0)	+(**)	[illegible]	[illegible]	1(**)
Berberis repens	2(**)	3(**)	8(2)	1(10)	4([illegible]	[illegible]	7(5)	6(4)	5(5)	[illegible]	[illegible]	4(2)
Ceanothus velutinus	–(0)	3([illegible]	1(**)	(0)	–([illegible]	3(11)	2(**)	3(13)	[illegible]	[illegible]	[illegible]	5(4)
Crataegus douglasii	–(0)	–(0)	–(0)	(0)	–([illegible]	1(**)	1(19)	–(0)	1(2)	[illegible]	[illegible]	–(0)
Juniperus communis	–(0)	(0)	–(0)	(0)	–(0)	1(**)	–(0)	–(0)	+(3)	[illegible]	[illegible]	–(0)
Pachistima myrsinites	[illegible]	[illegible]	4(10)	[illegible]	–(0)	2(18)	10(38)	3(2)	3(2)	[illegible]	[illegible]	10(36)
Physocarpus malvaceus	–(0)	–(0)	–(0)	(0)	–(0)	–(0)	+(3)	1(3)	[illegible]	[illegible]	[illegible]	–(0)
Prunus virginiana	(0)	–(0)	7(33)	[illegible]	[illegible]	1(**)	7(17)	8(13)	7(20)	[illegible]	[illegible]	3(1)
Rubus parviflorus	(0)	3(**)	–(0)	[illegible]	–(0)	2(13)	–(0)	–(0)	–(0)	[illegible]	[illegible]	–(0)
Rosa woodsii	5(**)	7(**)	8(3)	9(2)	[illegible]	4(5)	10(2)	10(5)	8(5)	[illegible]	[illegible]	6(1)
Salix scouleriana	[illegible]	[illegible]	4(6)	3(**)	[illegible]	–(0)	2(1)	5(2)	+(2)	[illegible]	[illegible]	[illegible]
Shepherdia canadensis	(0)	–(0)	–(0)	[illegible]	[illegible]	–(0)	2(9)	–(0)	+(8)	[illegible]	[illegible]	5(9)
Sorbus scopulina	(0)	7(**)	3(2)	(0)	[illegible]	[illegible]	2(1)	[illegible]	+(2)	[illegible]	[illegible]	2(1)
Spiraea betulifolia	(0)	3(**)	4(10)	(0)	–(0)	2(3)	2(16)	10(46)	+(4)	[illegible]	[illegible]	1(**)
Symphoricarpos albus	(0)	–(0)	7(7)	4(18)	[illegible]	4(6)	4(9)	10(15)	5(27)	[illegible]	[illegible]	–(0)
Symphoricarpos oreophilus	10(22)	7([illegible]	3(8)	6(27)	[illegible]	4(16)	6(11)	–(0)	6(27)	[illegible]	9(21)	9(17)
GRAMINOIDS												
Agropyron caninum	[illegible]	3([illegible]	3(**)	[illegible]	3(2)	2(3)	[illegible]	–(0)	3(1)	4(3)	3(5)	[illegible]
Agrostis spp.	(0)	–(0)	1(**)	[illegible]	–(0)	–(0)	–(0)	[illegible]	+(3)	–(0)	–(0)	–(0)
Bromus carinatus	[illegible]	3(2)	–(0)	3(10)	[illegible]	2(5)	[illegible]	–(0)	4(4)	3(2)	–(0)	5(4)
Bromus ciliatus	2(3)	–(0)	–(0)	(0)	[illegible]	–(0)	–(0)	–(0)	1(2)	1(**)	1(**)	[illegible]
Bromus spp.	(0)	–(0)	–(0)	1(3)	–(0)	–(0)	[illegible]	1(3)	[illegible]	[illegible]	1(**)	[illegible]
Calamagrostis rubescens	5(41)	3(**)	8(14)	10(30)	10(52)	10(43)	9(27)	10(14)	8(34)	10(35)	10(43)	5(5)
Carex aquatilis	(0)	–(0)	–(0)	(0)	[illegible]	–(0)	+(20)	–(0)	–(0)	–(0)	–(0)	–(0)
Carex geyeri	3(7)	[illegible]	2(10)	1(38)	6(13)	4(13)	3(34)	3(5)	2(12)	1(19)	1(38)	1(3)
Carex hoodii	2(**)	[illegible]	–(0)	1(3)	–(0)	[illegible]	[illegible]	[illegible]	3(2)	2(2)	–(0)	1(5)
Carex spp.	2(**)	–(0)	–(0)	[illegible]	[illegible]	–(0)	[illegible]	(0)	[illegible]	–(0)	–(0)	3(1)
Dactylis glomerata	(0)	[illegible]	–(0)	(0)	[illegible]	–(0)	–(0)	(0)	–(0)	–(0)	–(0)	–(0)
Elymus glaucus	3(2)	3([illegible]	9(19)	8(12)	4(**)	6(8)	7(6)	8(9)	9(7)	9(13)	3(3)	6(6)

Code of constancy values + = [illegible] 5, 1 = 5-15, 2 = 15-25, 3 = 25-35, 4 = 35-45, 5 = 45-55, 6 = 55-65, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

(con.)

Appendix A1. (con.)

Community Type:	POTR-ABLA/SYOR	POTR-ABLA/THFE	POTR-PSME/AMAL	POTR-PSME/SYOR	POTR-PSME/CARU	POTR-PICO/CARU	POTR/AMAL-PAMY	POTR/AMAL-SPBE	POTR/AMAL-SYOR	POTR/AMAL-CARU	POTR/PAMY-CARU	POTR/PAMY-GEVI
No. of stands:	6	3	9	8	7	10	25	8	53	20	7	17
Festuca idahoensis	–(0)	–(0)	–(0)	1(**)	1(**)	–(0)	–(0)	–(0)	+(**)	1(**)	–(0)	–(0)
Melica spectabilis	2(**)	–(0)	1(**)	4(**)	3(1)	2(**)	+(**)	1(**)	2(1)	2(**)	1(**)	1(**)
Phleum pratense	2(**)	–(0)	–(0)	1(**)	–(0)	1(**)	–(0)	–(0)	2(2)	–(0)	–(0)	–(0)
Poa palustris	2(**)	–(0)	–(0)	–(0)	1(**)	1(**)	+(**)	–(0)	1(**)	2(1)	–(0)	1(**)
Poa pratensis	5(1)	–(0)	1(**)	3(3)	3(2)	3(3)	2(3)	3(5)	5(14)	3(26)	3(3)	2(1)
Poa reflexa	2(**)	3(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	1(**)	1(**)	1(**)
Poa spp.	–(0)	3(**)	–(0)	3(2)	–(0)	1(**)	1(2)	–(0)	1(5)	–(0)	1(3)	2(**)
Stipa occidentalis	2(**)	–(0)	1(**)	–(0)	1(**)	–(0)	+(**)	–(0)	1(4)	–(0)	–(0)	1(**)
FORBS												
Achillea millefolium	10(1)	3(**)	6(**)	10(2)	10(1)	5(3)	6(2)	3(2)	7(1)	6(2)	4(2)	5(1)
Agastache urticifolia	5(6)	7(**)	1(**)	4(1)	–(0)	–(0)	1(5)	3(**)	2(3)	3(4)	–(0)	2(1)
Agoseris glauca	2(**)	–(0)	–(0)	1(**)	1(**)	1(**)	+(**)	–(0)	1(**)	1(**)	1(**)	1(**)
Antennaria microphylla	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	4(**)	1(**)
Aquilegia coerulea	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(3)	–(0)
Arabis spp.	3(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	1(**)	1(**)	1(**)
Arnica cordifolia	5(4)	7(3)	4(30)	5(9)	9(18)	4(9)	5(9)	1(**)	1(7)	3(11)	3(5)	6(9)
Artemisia ludoviciana	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(2)	1(**)	–(0)	–(0)
Aster perelegans	2(**)	–(0)	–(0)	1(**)	1(**)	–(0)	1(4)	–(0)	1(2)	1(**)	–(0)	–(0)
Aster engelmannii	–(0)	3(5)	7(8)	4(**)	–(0)	2(1)	4(6)	3(5)	2(3)	5(2)	4(2)	4(2)
Aster foliaceus	3(**)	–(0)	–(0)	–(0)	1(**)	2(4)	+(2)	5(1)	2(3)	2(1)	–(0)	1(**)
Aster integrifolius	–(0)	–(0)	–(0)	3(**)	–(0)	–(0)	–(0)	–(0)	1(1)	–(0)	–(0)	–(0)
Aster spp.	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	+(3)	1(**)	1(1)	1(2)	1(**)	1(**)
Astragalus miser	2(**)	–(0)	–(0)	–(0)	3(2)	–(0)	–(0)	–(0)	+(2)	1(3)	–(0)	1(**)
Balsamorhiza macrophylla	–(0)	–(0)	–(0)	–(0)	1(**)	1(20)	–(0)	–(0)	1(5)	1(**)	–(0)	2(**)
Campanula rotundifolia	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	2(**)	1(**)	+(**)	2(1)	–(0)	–(0)
Castilleja linariaefolia	–(0)	3(2)	1(**)	1(**)	4(**)	3(1)	2(**)	–(0)	2(**)	2(**)	3(**)	2(1)
Castilleja miniata	2(**)	–(0)	1(**)	3(2)	1(**)	–(0)	1(1)	–(0)	1(2)	–(0)	3(**)	–(0)
Clematis columbiana	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	1(**)	5(2)	1(**)	–(0)	–(0)	–(0)
Collinsia parviflora	2(**)	–(0)	1(**)	3(3)	1(3)	–(0)	+(3)	1(10)	2(4)	1(3)	–(0)	1(**)
Delphinium occidentale	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	+(**)	1(**)	2(2)	1(**)	–(0)	–(0)
Disporum trachycarpum	–(0)	–(0)	2(**)	–(0)	–(0)	–(0)	1(**)	3(1)	1(1)	1(1)	–(0)	–(0)
Epilobium angustifolium	–(0)	7(1)	4(1)	1(20)	3(**)	3(7)	5(2)	3(8)	2(2)	4(9)	4(1)	1(15)
Equisetum laevigatum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(20)	–(0)	–(0)	–(0)	–(0)	–(0)
Erigeron speciosus	7(4)	3(15)	1(**)	3(2)	–(0)	1(10)	2(2)	3(**)	3(1)	1(**)	1(**)	1(**)
Fragaria vesca	7(6)	10(4)	7(2)	6(3)	9(2)	3(2)	3(2)	–(0)	3(2)	4(1)	1(38)	4(1)
Frasera speciosa	–(0)	–(0)	–(0)	3(2)	1(**)	2(2)	2(**)	–(0)	1(**)	1(1)	3(2)	1(3)
Galium boreale	2(**)	7(**)	1(**)	5(3)	1(2)	4(**)	2(1)	–(0)	3(2)	3(2)	1(3)	1(**)
Galium triflorum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(4)	–(0)	+(5)	1(**)	–(0)	–(0)
Geranium richardsonii	(0)	–(0)	–(0)	1(30)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Geranium viscosissimum	10(25)	10(11)	8(4)	10(24)	10(10)	10(14)	9(6)	8(8)	10(12)	10(10)	10(10)	9(16)
Habenaria unalascensis	7(**)	–(0)	2(**)	3(**)	–(0)	3(1)	3(**)	3(**)	3(**)	2(**)	–(0)	4(**)
Hackelia floribunda	2(**)	3(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	1(**)	–(0)	–(0)
Helenium hoopsii	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Helianthella uniflora	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	1(**)	2(1)	2(1)	–(0)	–(0)
Heracleum lanatum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	1(**)	–(0)	–(0
Hieracium albiflorum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	2(1)	–(0)	+(**)	–(0)	–(0)	1(2
Hieracium cynoglossoides	–(0)	–(0)	3(**)	4(**)	4(**)	2(2)	2(**)	1(**)	3(**)	2(**)	3(**)	1(**
Iris missouriensis	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0
Lathyrus lanszwertii	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0
Ligusticum filicinum	–(0)	–(0)	–(0)	1(3)	–(0)	3(5)	+(**)	–(0)	2(7)	1(17)	–(0)	–(0

(con

Appendix A1. (con.)

Community Type:	POTR-ABLA/SYOR	POTR-ABLA/THFE	POTR-PSME/AMAL	POTR-PSME/SYOR	POTR-PSME/CARU	POTR-PICO/CARU	POTR/AMAL-PAMY	POTR/AMAL-SPBE	POTR/AMAL-SYOR	POTR/AMAL-CARU	POTR/PAMY-CARU	POTR/PAMY-GEVI
No. of stands:	6	3	9	8	7	10	25	8	53	20	7	17
Lupinus argenteus	10(3)	7(**)	6(5)	9(5)	10(5)	7(4)	9(7)	9(4)	7(8)	9(9)	10(5)	5(5)
Nemophila breviflora	2(10)	–(0)	1(**)	3(15)	–(0)	(0)	–(0)	–(0)	1(21)	–(0)	(0)	–(0)
Osmorhiza chilensis	8(3)	10(9)	9(7)	10(5)	7(4)	8(3)	7(11)	8(5)	7(6)	7(10)	9(2)	7(3)
Osmorhiza occidentalis	7(2)	3(**)	2(2)	1(**)	–(0)	1(2)	2(1)	–(0)	3(5)	3(3)	(0)	1(5)
Paeonia brownii	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(1)	1(**)	(0)	–(0)
Pedicularis bracteosa	–(0)	–(0)	–(0)	3(**)	–(0)	4(2)	–(0)	1(**)	1(**)	1(3)	(0)	–(0)
Pedicularis racemosa	–(0)	–(0)	–(0)	–(0)	(0)	–(0)	–(0)	–(0)	+(**)	–(0)	(0)	–(0)
Perideridia gairdneri	–(0)	–(0)	3(**)	4(**)	7(1)	4(1)	3(**)	8(1)	5(**)	7(1)	1(**)	(0)
Potentilla glandulosa	3(**)	3(**)	3(**)	4(**)	6(**)	4(1)	2(1)	–(0)	5(1)	3(1)	7(8)	6(2)
Potentilla gracilis	2(**)	–(0)	–(0)	1(3)	–(0)	2(1)	1(2)	–(0)	2(1)	1(5)	1(**)	–(0)
Pteridium aquilinum	–(0)	–(0)	1(35)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	(0)	–(0)
Rudbeckia occidentalis	2(2)	7(5)	–(0)	3(21)	–(0)	1(15)	+(3)	–(0)	2(11)	2(12)	(0)	–(0)
Scrophularia lanceolata	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	(0)	–(0)
Senecio crassulus	2(10)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)	1(**)	1(10)	(0)	–(0)
Senecio streptanthifolius	5(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	1(**)	1(**)	1(**)	1(**)	2(**)
Senecio integerrimus	2(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(3)	1(4)	(0)	–(0)
Senecio serra	5(**)	7(**)	–(0)	–(0)	–(0)	1(5)	+(**)	4(1)	3(5)	3(7)	(0)	1(3)
Silene menziesii	2(**)	–(0)	2(**)	1(**)	–(0)	–(0)	2(3)	–(0)	1(1)	1(2)	3(2)	1(**)
Smilacina racemosa	2(**)	–(0)	2(**)	1(**)	3(**)	–(0)	4(1)	8(1)	2(3)	3(3)	(0)	1(**)
Smilacina stellata	–(0)	–(0)	7(1)	1(**)	1(**)	2(3)	2(2)	8(2)	3(1)	3(3)	4(1)	1(**)
Solidago canadensis	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	(0)	–(0)
Stellaria jamesiana	2(**)	–(0)	–(0)	1(3)	–(0)	1(**)	+(3)	–(0)	+(2)	1(**)	(0)	3(3)
Taraxacum officinale	8(2)	7(1)	3(**)	5(1)	6(2)	4(1)	5(2)	3(**)	7(2)	6(2)	4(2)	2(**)
Thalictrum fendleri	5(9)	10(15)	10(19)	10(11)	10(13)	7(7)	9(7)	10(13)	7(12)	8(14)	4(1)	5(5)
Tragopogon dubius	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	2(**)	1(**)	–(0)
Trifolium dubium	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	(0)	–(0)
Trifolium repens	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	–(0)	–(0)
Trifolium spp.	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(5)	–(0)	+(3)	–(0)	(0)	–(0)
Valeriana occidentalis	2(**)	3(**)	2(**)	5(8)	–(0)	1(**)	+(5)	1(**)	3(3)	3(5)	1(**)	2(4)
Vicia americana	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	(0)	(0)	–(0)
Viola adunca	2(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	1(**)	1(**)	3(**)	–(0)
Viola nuttallii	3(**)	–(0)	–(0)	–(0)	–(0)	1(**)	+(**)	–(0)	1(1)	2(**)	(0)	1(**)
Viola spp.	2(**)	3(10)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(2)	1(**)	(0)	–(0)
Wyethia amplexicaulis	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	1(**)	–(0)	–(0)	1(**)

Code of constancy values: + = < 5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

APPENDIX A2

Appendix A2. Constancy and average canopy cover (latter in parenthesis) of important plants in aspen community types within the Caribou and Targhee National Forests. (Code for constancy values is at the bottom of the table; canopy cover is the average percent for those stands in which the species was found, except "**" denotes a trace value.)

Community Type:	POTR/ SPBE-CARU	POTR/ SYOR-CARU	POTR/ SYOR-POPR	POTR/ SYOR-RUOC	POTR/ ARTR-FEID	POTR/ GEVI	POTR/ WYAM	POTR/ CARU	POTR/ CARU-POPR	POTR/ POPR	POTR/ RUOC
No. of stands:	3	42	15	8	2	5	7	35	13	12	4
TREES											
Abies lasiocarpa > 1.5 m tall	–(0)	1(1)	2(2)	–(0)	–(0)	2(2)	1(**)	1(4)	1(**)	2(8)	5(8)
Abies lasiocarpa < 1.5 m tall	–(0)	1(**)	1(1)	1(1)	–(0)	2(**)	1(**)	1(**)	1(**)	3(2)	10(**)
Juniperus scopulorum > 1.5 m	–(0)	1(2)	–(0)	1(**)	–(0)	–(0)	1(1)	+(**)	–(0)	–(0)	–(0)
Juniperus scopulorum < 1.5 m	3(**)	1(**)	1(**)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Picea engelmannii > 1.5 m	–(0)	+(7)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	–(0)	–(0)
Picea engelmannii < 1.5 m	–(0)	+(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Pinus contorta > 1.5 m	–(0)	3(3)	2(2)	–(0)	–(0)	–(0)	3(**)	2(1)	1(**)	1(**)	–(0)
Pinus contorta < 1.5 m	–(0)	2(**)	1(**)	1(**)	–(0)	–(0)	1(**)	2(**)	1(**)	1(**)	–(0)
Populus tremuloides > 1.5 m	10(80)	10(76)	10(76)	10(68)	10(70)	10(65)	10(74)	10(79)	10(80)	10(77)	10(76)
Populus tremuloides < 1.5 m	7(5)	10(7)	10(5)	10(2)	10(43)	10(4)	9(2)	10(6)	10(7)	10(6)	10(2)
Pseudotsuga menziesii > 1.5 m	3(**)	2(3)	1(3)	4(3)	5(**)	4(3)	3(1)	4(3)	1(**)	3(3)	–(0)
Pseudotsuga menziesii < 1.5 m	7(**)	3(1)	3(1)	1(**)	5(**)	2(**)	1(**)	3(**)	3(1)	1(**)	–(0)
SHRUBS											
Acer glabrum	–(0)	–(0)	1(**)	–(0)	–(0)	2(5)	–(0)	–(0)	–(0)	–(0)	–(0)
Acer grandidentatum	–(0)	–(0)	1(3)	1(**)	–(0)	–(0)	1(**)	+(**)	–(0)	–(0)	–(0)
Amelanchier alnifolia	7(**)	7(2)	5(1)	6(1)	–(0)	4(3)	6(2)	4(1)	2(1)	3(2)	5(4)
Artemisia tridentata	–(0)	+(**)	1(**)	1(**)	10(5)	2(**)	1(**)	1(1)	2(**)	–(0)	3(**)
Berberis repens	10(6)	6(2)	3(1)	4(1)	5(5)	–(0)	1(**)	4(2)	4(5)	3(2)	–(0)
Ceanothus velutinus	7(2)	+(13)	–(0)	–(0)	–(0)	–(0)	–(0)	+(8)	–(0)	1(**)	–(0)
Crataegus douglasii	–(0)	1(1)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	–(0)	–(0)
Juniperus communis	–(0)	+(6)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)
Pachistima myrsinites	—(0)	2(1)	2(3)	–(0)	–(0)	2(2)	–(0)	1(**)	–(0)	1(2)	–(0)
Physocarpus malvaceus	–(0)	+(9)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Prunus virginiana	10(3)	3(1)	1(7)	4(**)	–(0)	–(0)	–(0)	1(1)	1(3)	–(0)	5(2)
Rubus parviflorus	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Rosa woodsii	7(**)	6(3)	5(10)	4(13)	5(**)	4(5)	3(**)	3(1)	5(1)	5(1)	5(**)
Salix scouleriana	3(**)	1(2)	–(0)	1(**)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)
Shepherdia canadensis	–(0)	+(**)	1(2)	–(0)	–(0)	–(0)	1(4)	1(6)	1(**)	1(20)	–(0)
Sorbus scopulina	–(0)	+(2)	–(0)	1(**)	–(0)	–(0)	–(0)	1(4)	–(0)	–(0)	–(0)
Spiraea betulifolia	10(31)	1(2)	–(0)	–(0)	–(0)	–(0)	–(0)	+(2)	–(0)	–(0)	–(0)
Symphoricarpos albus	10(27)	5(27)	2(20)	1(38)	–(0)	–(0)	–(0)	1(4)	2(2)	2(2)	–(0)
Symphoricarpos oreophilus	–(0)	5(18)	9(22)	9(24)	–(0)	6(6)	6(1)	8(2)	4(2)	6(1)	10(1)
GRAMINOIDS											
Agropyron caninum	–(0)	5(1)	7(3)	4(25)	5(**)	2(3)	3(3)	5(2)	8(1)	5(4)	5(5)
Agrostis spp.	–(0)	+(5)	–(0)	–(0)	–(0)	4(25)	1(**)	+(**)	2(**)	–(0)	3(**)
Bromus carinatus	–(0)	3(1)	6(5)	8(10)	–(0)	4(10)	6(2)	5(2)	5(1)	2(8)	5(3)
Bromus ciliatus	–(0)	1(2)	1(3)	–(0)	–(0)	–(0)	–(0)	1(1)	2(**)	3(1)	3(3)
Bromus spp.	–(0)	1(2)	1(**)	–(0)	–(0)	–(0)	–(0)	+(**)	2(**)	2(**)	3(10)
Calamagrostis rubescens	10(37)	10(44)	3(6)	–(0)	–(0)	4(4)	3(13)	10(48)	10(42)	2(3)	–(0)
Carex aquatilis	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Carex geyeri	–(0)	2(35)	3(1)	–(0)	–(0)	–(0)	1(20)	2(37)	1(10)	1(**)	–(0)
Carex hoodii	3(**)	1(1)	3(2)	5(2)	–(0)	–(0)	3(**)	1(2)	2(1)	3(10)	–(0)
Carex spp.	–(0)	+(**)	–(0)	–(0)	5(**)	2(**)	1(**)	–(0)	–(0)	–(0)	3(**)
Dactylis glomerata	–(0)	1(2)	–(0)	3(**)	–(0)	–(0)	3(2)	+(**)	2(**)	–(0)	3(**)
Elymus glaucus	10(1)	7(10)	5(5)	5(24)	–(0)	6(17)	4(9)	5(12)	2(10)	5(18)	8(6)
Festuca idahoensis	–(0)	+(**)	2(**)	–(0)	10(30)	–(0)	4(1)	2(1)	1(3)	–(0)	–(0)
Melica spectabilis	–(0)	2(**)	1(**)	4(**)	–(0)	4(**)	1(**)	1(**)	2(**)	3(**)	5(**
Phleum pratense	–(0)	1(1)	1(**)	1(40)	–(0)	2(**)	4(2)	2(1)	4(7)	2(5)	–(0

(cor)

Appendix A2. (con.)

Community Type:	POTR/ SPBE-CARU	POTR/ SYOR-CARU	POTR/ SYOR-POPR	POTR/ SYOR-RUOC	POTR/ ARTR-FEID	POTR/ GEVI	POTR/ WYAM	POTR/ CARU	POTR/ CARU-POPR	POTR/ POPR	POTR/ RUOC
No. of stands:	3	42	15	8	2	5	7	35	13	12	4
Poa palustris	–(0)	1(1)	1(75)	–(0)	–(0)	–(0)	3(3)	2(11)	2(**)	1(3)	–(0)
Poa pratensis	3(2)	5(17)	9(40)	8(11)	5(10)	4(2)	9(12)	5(6)	10(32)	10(49)	[illegible]
Poa reflexa	–(0)	–(0)	–(0)	1(3)	–(0)	–(0)	–(0)	+(**)	–(0)	2(3)	3(3)
Poa spp.	–(0)	+(**)	–(0)	(0)	5(5)	–(0)	1(**)	1(16)	–(0)	–(0)	[illegible]
Stipa occidentalis	–(0)	2(1)	3(**)	(0)	10(8)	2(5)	1(2)	2(2)	4(1)	3(1)	3(**)
FORBS											
Achillea millefolium	7(**)	8(2)	6(1)	9(3)	5(3)	4(**)	6(**)	8(1)	8(1)	8(**)	[illegible]
Agastache urticifolia	3(**)	2(1)	3(2)	6(7)	(0)	4(1)	–(0)	+(**)	–(0)	1(10)	[illegible]
Agoseris glauca	3(**)	1(**)	–(0)	1(**)	–(0)	2(**)	–(0)	1(**)	1(**)	2(**)	–(0)
Antennaria microphylla	–(0)	–(0)	2(**)	–(0)	5(**)	–(0)	1(**)	1(2)	4(1)	1(**)	–(0)
Aquilegia coerulea	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	1(**)	2(9)	[illegible]
Arabis spp.	3(**)	+(**)	1(**)	1(**)	–(0)	2(**)	–(0)	–(0)	1(**)	–(0)	[illegible]
Arnica cordifolia	–(0)	3(7)	1(4)	–(0)	–(0)	2(20)	–(0)	3(9)	2(3)	3(17)	[illegible]
Artemisia ludoviciana	–(0)	+(3)	1(**)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	1(**)	–(0)
Aster perelegans	3(3)	1(3)	1(**)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)
Aster engelmannii	–(0)	1(1)	–(0)	–(0)	–(0)	4(3)	–(0)	3(3)	–(0)	–(0)	[illegible]
Aster foliaceus	3(**)	2(2)	–(0)	3(12)	–(0)	2(**)	–(0)	1(1)	4(1)	1(**)	–(0)
Aster integrifolius	–(0)	1(4)	–(0)	–(0)	–(0)	2(**)	1(**)	+(3)	–(0)	2(**)	–(0)
Aster spp.	–(0)	2(1)	2(**)	–(0)	–(0)	–(0)	–(0)	1(1)	2(**)	1(**)	–(0)
Astragalus miser	–(0)	1(4)	3(1)	–(0)	–(0)	–(0)	1(3)	3(4)	3(1)	2(**)	–(0)
Balsamorhiza macrophylla	–(0)	+(**)	–(0)	–(0)	–(0)	2(3)	4(2)	+(**)	–(0)	1(**)	3(**)
Campanula rotundifolia	–(0)	2(**)	1(**)	1(**)	–(0)	–(0)	–(0)	1(**)	2(**)	–(0)	–(0)
Castilleja linariaefolia	–(0)	1(**)	–(0)	1(**)	–(0)	2(**)	–(0)	1(1)	1(10)	–(0)	[illegible]
Castilleja miniata	–(0)	1(1)	1(**)	–(0)	–(0)	–(0)	(0)	1(**)	1(**)	–(0)	–(0)
Clematis columbiana	–(0)	1(4)	1(**)	–(10)	–(0)	–(0)	–(0)	+(**)	–(0)	–(0)	[illegible]
Collinsia parviflora	–(0)	1(9)	1(10)	4(20)	–(0)	–(0)	1(**)	1(**)	1(3)	2(2)	3(**
Delphinium occidentale	–(0)	1(1)	1(2)	4(**)	–(0)	–(0)	1(**)	1(**)	–(0)	1(**)	3(10)
Disporum trachycarpum	–(0)	+(**)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	1(**)	–(0)	–(0)
Epilobium angustifolium	3(1)	3(10)	–(0)	–(0)	–(0)	4(8)	–(0)	1(**)	–(0)	1(3)	3(**
Equisetum laevigatum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)
Erigeron speciosus	–(0)	4(2)	3(3)	4(1)	–(0)	2(5)	3(1)	+(**)	1(**)	1(2)	–(0)
Fragaria vesca	–(0)	5(2)	6(3)	6(1)	5(15)	2(**)	3(4)	5(4)	5(3)	5(4)	5(1[illegible]
Frasera speciosa	–(0)	1(2)	2(**)	(0)	–(0)	–(0)	1(**)	2(1)	2(**)	1(2)	3(**
Galium boreale	–(0)	4(2)	2(1)	4(1)	–(0)	4(3)	1(**)	2(1)	4(1)	3(1)	3(**
Galium triflorum	–(0)	+(**)	–(0)	(0)	–(0)	–(0)	–(0)	1(2)	–(0)	–(0)	–([illegible]
Geranium richardsonii	–(0)	–(0)	–(0)	1(20)	–(0)	–(0)	–(0)	–(0)	–(0)	[illegible]	[illegible]
Geranium viscosissimum	7(6)	10(14)	10(14)	4(9)	10(3)	10(20)	10(9)	10(12)	9(10)	8(13)	[illegible]
Habenaria unalascensis	–(0)	1(**)	1(**)	–(0)	–(0)	–(0)	4(**)	1(1)	2(**)	1(**	[illegible]
Hackelia floribunda	–(0)	1(2)	1(**)	5(4)	–(0)	4(2)	–(0)	1(1)	–(0)	–(0)	5(**
Helenium hoopsii	–(0)	–(0)	1(**)	1(5)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–([illegible]
Helianthella uniflora	–(0)	1(3)	–(0)	–(0)	–(0)	–(0)	1(**)	–(0)	–(0)	–(0)	[illegible]
Heracleum lanatum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	(0)	–(0)	–(0)	–(0)	[illegible]
Hieracium albiflorum	–(0)	+(**)	1(**)	–(0)	(0)	2(**)	–(0)	1(**)	–(0)	–(0)	–([illegible]
Hieracium cynoglossoides	7(**)	3(**)	1(**)	–(0)	5(**)	–(0)	–(0)	2(**)	2(**	–(0)	[illegible]
Iris missouriensis	–(0)	–(0)	–(0)	–(0)	(0)	–(0)	–(0)	–(0)	2(2)	1(**)	[illegible]
Lathyrus lanszwertii	–(0)	–(0)	–(0)	3(19)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	[illegible]
Ligusticum filicinum	–(0)	+(**)	–(0)	–(0)	–(0)	–(0)	3(5)	1(19)	–(0)	–(0)	[illegible]
Lupinus argenteus	7(6)	8(7)	8(8)	5(**)	10(4)	4(23)	3(10)	9(9)	6(7)	7(5)	[illegible]
Nemophila breviflora	–(0)	1(21)	1(**)	5(66)	–(0)	2(20)	–(0)	[illegible]	1(3)	1(20)	[illegible]
Osmorhiza chilensis	7(2)	7(6)	6(5)	6(7)	–(0)	8(16)	3(4)	7(4)	6(3)	7(3)	[illegible]

Code of constancy values: + = <5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

(con.)

Appendix A2. (con.)

Community Type:	POTR/ SPBE-CARU	POTR/ SYOR-CARU	POTR/ SYOR-POPR	POTR/ SYOR-RUOC	POTR/ ARTR-FEID	POTR/ GEVI	POTR/ WYAM	POTR/ CARU	POTR/ CARU-POPR	POTR/ POPR	POTR/ RUOC
No. of stands:	3	42	15	8	2	5	7	35	13	12	4
Osmorhiza occidentalis	–(0)	1(8)	2(1)	3(3)	–(0)	4(4)	3(13)	1(1)	–(0)	2(3)	5(7)
Paeonia brownii	–(0)	+(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Pedicularis bracteosa	–(0)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(1)	–(0)	1(**)	3(**)
Pedicularis racemosa	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	5(**)
Perideridia gairdneri	7(**)	5(1)	3(1)	–(0)	5(**)	4(**)	4(**)	5(1)	8(1)	6(1)	–(0)
Potentilla glandulosa	3(**)	5(1)	5(**)	1(3)	5(5)	6(2)	1(1)	6(1)	7(1)	6(**)	3(**)
Potentilla gracilis	–(0)	1(2)	3(5)	4(1)	–(0)	6(**)	3(**)	3(2)	4(4)	5(1)	3(**)
Pteridium aquilinum	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	+(5)	–(0)	–(0)	–(0)
Rudbeckia occidentalis	–(0)	2(5)	3(1)	10(34)	–(0)	4(2)	4(8)	1(3)	2(8)	3(11)	10(29)
Scrophularia lanceolata	–(0)	–(0)	1(**)	4(**)	–(0)	2(**)	–(0)	–(0)	–(0)	–(0)	–(0)
Senecio crassulus	–(0)	+(5)	1(10)	–(0)	–(0)	2(**)	–(0)	1(1)	1(3)	2(2)	3(3)
Senecio streptanthifolius	–(0)	+(**)	2(**)	1(**)	–(0)	–(0)	–(0)	1(**)	–(0)	2(**)	3(**)
Senecio integerrimus	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	1(5)	–(0)	1(**)	–(0)	–(0)
Senecio serra	–(0)	2(2)	3(2)	8(10)	–(0)	4(1)	1(**)	1(**)	1(**)	3(**)	3(20)
Silene menziesii	3(3)	1(1)	1(3)	1(3)	–(0)	–(0)	–(0)	2(1)	–(0)	–(0)	3(3)
Smilacina racemosa	7(2)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(**)	2(**)	–(0)	–(0)
Smilacina stellata	7(1)	3(2)	1(3)	1(**)	–(0)	2(**)	–(0)	3(2)	2(**)	2(**)	–(0)
Solidago canadensis	–(0)	1(2)	–(0)	–(0)	–(0)	–(0)	–(0)	+(**)	–(0)	1(10)	–(0)
Stellaria jamesiana	–(0)	1(2)	–(0)	5(5)	–(0)	2(3)	–(0)	1(**)	–(0)	–(0)	8(2)
Taraxacum officinale	3(**)	7(2)	7(3)	4(2)	5(15)	2(1)	4(7)	6(2)	8(3)	8(4)	10(1)
Thalictrum fendleri	10(12)	5(10)	4(4)	8(4)	–(0)	8(9)	1(**)	7(8)	5(2)	6(5)	10(12)
Tragopogon dubius	–(0)	1(**)	1(2)	1(**)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Trifolium dubium	–(0)	+(3)	1(**)	1(**)	–(0)	–(0)	–(0)	–(0)	2(**)	–(0)	–(0)
Trifolium repens	–(0)	+(**)	–(0)	–(0)	–(0)	–(0)	–(0)	1(4)	–(0)	–(0)	–(0)
Trifolium spp.	–(0)	–(0)	1(3)	–(0)	–(0)	–(0)	–(0)	+(**)	1(**)	1(5)	–(0)
Valeriana occidentalis	–(0)	3(3)	3(9)	8(6)	–(0)	4(8)	–(0)	2(4)	2(3)	5(4)	5(5)
Vicia americana	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)	–(0)
Viola adunca	–(0)	1(**)	1(**)	3(**)	–(0)	–(0)	–(0)	1(1)	2(**)	1(**)	3(**)
Viola nuttallii	–(0)	+(**)	–(0)	–(0)	–(0)	2(**)	–(0)	2(1)	–(0)	2(**)	5(**)
Viola spp.	–(0)	+(**)	1(**)	1(3)	–(0)	–(0)	–(0)	1(1)	–(0)	–(0)	–(0)
Wyethia amplexicaulis	–(0)	+(**)	–(0)	–(0)	–(0)	2(**)	10(48)	+(**)	–(0)	1(**)	–(0)

Code of constancy values: + = < 5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

APPENDIX B1

Means, standard errors (SE), and ranges of basal area, stand age, stand height, and site index for *Populus tremuloides* by community types in English units.

Community type	Basal area	Stand age	Stand height	Site index (at 80 years)
	Ft²/acre	*Years*	*Feet*	
POTR-ABLA/SYOR (2)[1]				
mean	111	91	58	54
SE	37	3	8	8
range	73-150	88-94	49-66	45-62
POTR-PSME/AMAL (2)				
mean	152	88	50	53
SE	5	24	0	5
range	147-157	63-112	50-50	48-58
POTR-PSME/SYOR (3)				
mean	162	95	60	55
SE	37	1	5	8
range	114-236	94-96	49-65	46-60
POTR-PSME/CARU (1)				
mean	154	97	62	56
SE	—	—	—	—
range	—	—	—	—
POTR-PICO/CARU (1)				
mean	182	115	87	72
SE	—	—	—	—
range	—	—	—	—
POTR/AMAL-PAMY (12)				
mean	123	90	51	55
SE	7	6	3	3
range	77-165	47-107	35-67	38-71
POTR/AMAL-SPBE (3)				
mean	128	94	63	60
SE	16	6	2	5
range	95-144	83-100	60-65	53-70
POTR/AMAL-SYOR (20)				
mean	105	91	48	49
SE	6	4	2	2
range	36-158	53-125	33-67	36-65
POTR/AMAL-CARU (5)				
mean	141	72	45	49
SE	17	6	3	3
range	83-186	52-87	35-53	40-56
POTR/PAMY-CARU (3)				
mean	145	96	54	50
SE	4	10	8	6
range	136-150	78-112	39-68	40-60
POTR/PAMY-GEVI (2)				
mean	129	98	49	47
SE	0	2	1	1
range	129-129	96-100	48-50	46-48
POTR/SPBE-CARU (1)				
mean	160	106	53	46
SE				—
range		—	—	
POTR/SYOR-CARU (17)				
mean	138	85	52	51
SE	9	4	2	2
range	86-206	53-107	32-68	35-66
POTR/SYOR-POPR (5)				
mean	154	79	50	56
SE	14	8	2	4
range	112-187	49-94	47-57	45-65
POTR/SYOR-RUOC (5)				
mean	139	96	57	55
SE	15	9	4	6
range	109-194	64-119	46-68	43-77
POTR/GEVI (1)				
mean	164	120	65	52
SE	—	—	—	—
range	—	—	—	—
POTR/WYAM (2)				
mean	74	71	27	31
SE	38	8	3	4
range	36-112	63-79	24-30	27-35
POTR/CARU (12)				
mean	144	93	55	54
SE	9	3	3	2
range	61-185	75-112	38-69	40-65
POTR/CARU-POPR (5)				
mean	149	88	49	47
SE	12	8	8	5
range	113-182	67-114	33-75	37-65
POTR/POPR (4)				
mean	220	95	63	62
SE	26	10	1	5
range	168-280	67-110	60-66	51-72
POTR/RUOC (3)				
mean	106	97	55	54
SE	4	4	3	3
range	101-115	93-105	51-61	48-57
All intensively sampled stands (114)				
mean	135	90	52	52
SE	4	2	1	1
range	36-280	52-125	24-87	27-77

[1]Number of stands sampled

APPENDIX B2

Means, standard errors (SE), and ranges of basal area, stand age, stand height, and site index for *Populus tremuloides* by community types in metric units.

Community type	Basal area	Stand age	Stand height	Site index (at 80 years)
	m^2/ha	*Years*	-------- *Meters* --------	
POTR-ABLA/SYOR (2)[1]				
mean	25.5	91	17.7	16.5
SE	8.5	3	2.4	2.4
range	16.8-34.4	88-94	14.9-20.1	13.7-18.9
POTR-PSME/AMAL (2)				
mean	35.0	88	15.3	16.2
SE	1.1	24	0	1.5
range	33.8-36.0	63-112	15.3-15.3	14.6-17.7
POTR-PSME/SYOR (3)				
mean	37.2	95	18.3	16.8
SE	8.5	1	1.5	2.4
range	26.2-54.2	94-96	14.9-19.8	14.0-18.3
POTR-PSME/CARU (1)				
mean	35.4	97	18.9	17.1
SE	—	—	—	—
range	—	—	—	—
POTR-PICO/CARU (1)				
mean	41.8	115	26.5	21.9
SE	—	—	—	—
range	—	—	—	—
POTR/AMAL-PAMY (12)				
mean	28.2	90	15.5	16.8
SE	1.6	6	0.9	0.9
range	17.7-37.9	47-107	10.7-20.4	11.6-21.6
POTR/AMAL-SPBE (3)				
mean	29.4	94	19.2	18.3
SE	3.7	6	0.6	1.5
range	21.8-33.1	83-100	18.3-19.8	16.2-21.3
POTR/AMAL-SYOR (20)				
mean	24.1	91	14.6	14.9
SE	1.4	4	0.6	0.6
range	8.3-36.3	53-125	10.0-20.4	11.0-19.8
POTR/AMAL-CARU (5)				
mean	32.4	72	13.7	14.9
SE	3.9	6	0.9	0.9
range	19.1-42.7	52-87	10.7-16.2	12.2-17.1
POTR/PAMY-CARU (3)				
mean	33.3	96	16.6	15.2
SE	0.9	10	2.4	1.8
range	31.2-34.4	78-112	11.9-20.7	12.2-18.3
POTR/PAMY-GEVI (2)				
mean	29.6	98	14.9	14.3
SE	0.0	2	0.3	0.3
range	29.6-29.6	96-100	14.6-15.2	14.0-14.6

APPENDIX B2 (CON.)

Community type	Basal area	Stand age	Stand height	Site index (at 80 years)
	m^2/ha	*Years*	-------- *Meters* --------	
POTR/SPBE-CARU (1)				
mean	36.7	106	16.2	14.0
SE	—	—	—	—
range	—	—	—	—
POTR/SYOR-CARU (17)				
mean	31.7	85	15.8	15.5
SE	2.1	4	0.6	0.6
range	19.7-47.3	53-107	9.8-20.7	10.7-20.
POTR/SYOR-POPR (5)				
mean	35.4	79	15.2	17.1
SE	3.2	8	0.6	1.2
range	25.7-42.9	49-94	14.3-17.4	13.7-19
POTR/SYOR-RUOC (5)				
mean	31.9	96	17.4	16.8
SE	3.4	9	1.2	1.8
range	25.0-44.5	64-119	14.0-20.7	13.1-23
POTR/GEVI (1)				
mean	37.7	120	19.8	15.8
SE	—	—	—	—
range	—	—	—	—
POTR/WYAM (2)				
mean	17.0	71	8.2	9.4
SE	8.7	8	0.9	1.2
range	8.3-25.7	63-79	7.3-9.1	8.2-1
POTR/CARU (12)				
mean	33.1	93	16.8	16.4
SE	2.1	3	0.9	0.6
range	14.0-42.5	75-112	11.6-21.0	12.2-1
POTR/CARU-POPR (5)				
mean	34.2	88	14.9	14.3
SE	2.8	8	2.4	1.5
range	25.9-41.8	67-114	10.1-22.9	11.3-1
POTR/POPR (4)				
mean	50.5	95	19.2	18.9
SE	6.0	10	0.3	1.5
range	38.6-64.3	67-110	18.3-20.1	15.5-2
POTR/RUOC (3)				
mean	24.3	97	16.8	16.5
SE	0.9	4	0.9	0.9
range	23.2-26.4	93-105	15.5-18.6	14.6-7
All intensively sampled stands (114)				
mean	31.0	90	15.8	15.8
SE	0.9	2	0.3	0.3
range	8.3-64.3	52-125	7.3-26.5	8.2-2

[1]Number of stands sampled.

APPENDIX C

Means, standard errors (SE) and ranges of total dry undergrowth production, composition by vegetation classes, and suitability of the undergrowth as livestock forage

Community type	N[1]	Total production		Composition: Shrubs	Forbs	Graminoids	N[2]	Forage suitability: Desirable	Intermediate	Least
				(Percent of total production)				(Percent of total canopy-cover)		
		Lb/acre	*Kg/ha*							
POTR-ABLA/SYOR	2						6			
mean		402	(451)	14	67	19		54	42	4
SE		92	(103)	6	2	4		—	—	—
range		310-494	(348-554)	7-20	65-70	15-23		—	—	—
POTR-ABLA/THFE	0						3			
mean		—	—	—	—	—		53	47	—
SE		—	—	—	—	—		—	—	—
range		—	—	—	—	—				
POTR-PSME/AMAL	2						9			
mean		1,079	(1 210)	35	47	18		50	40	—
SE		307	(344)	15	17	2		—		—
range		772-1,386	(865-1 554)	20-50	30-65	15-20				
POTR-PSME/SYOR	3						8			
mean		934	(1 047)	3	53	44		54	36	10
SE		218	(244)	1	15	15		—	—	—
range		558-1,313	(626-1 472)	1-5	25-74	25-73				
POTR-PSME/CARU	1						7			
mean		498	(558)	1	35	64		62	37	1
SE		—		—	—	—		—		
range		—	—	—	—	—		—	—	—
POTR-PICO/CARU	1						10			
mean		707	(793)	1	25	74		73	26	1
SE		—	—	—	—					
range		—	—		—	—			—	—
POTR/AMAL-PAMY	12						25			
mean		846	(948)	40	31	29		56	37	7
SE		98	(110)	4	3	4		—	—	—
range		337-1,430	(378-1 603)	15-65	20-50	10-65				
POTR/AMAL-SPBE	3						6			
mean		1,008	(1 130)	58	25	17		48	51	1
SE		146	(164)	17	6	12		—	—	
range		821-1,296	(920-1 453)	25-80	15-35	5-40				
POTR/AMAL-SYOR	20						53			
mean		979	(1 097)	16	42	42		56	41	3
SE		75	(84)	2	3	4			—	—
range		244-1,517	(274-1 701)	3-40	17-80	8-75				
POTR/AMAL-CARU	5						20			
mean		1,035	(1 160)	7	42	51		57	41	2
SE		109	(122)	3	3	4			—	
range		738-1,333	(827-1 494)	1-15	38-52	40-60		—		
POTR/PAMY-CARU	3						7			
mean		639	(716)	20	37	43		58	34	1
SE		43	(48)	9	6	6		—		—
range		591-724	(663-812)	5-35	25-45	35-55		—		—
POTR/PAMY-GEVI	2						17			
mean		508	(569)	21	65	14		51	39	10
SE		47	(53)	4	10	6				
range		461-556	(517-623)	17-25	55-75	8-20				

Appendix C (con.)

Community type	N[1]	Total production		Composition: Shrubs	Forbs	Graminoids	N[2]	Forage suitability: Desirable	Intermediate	Least
				(Percent of total production)				(Percent of total canopy-cover)		
		Lb/acre	*Kg/ha*							
POTR/SPBE-CARU	1						3			
mean		847	(949)	25	35	40		53	45	2
SE		—	—	—	—	—		—	—	—
range		—	—	—	—	—		—	—	—
POTR/SYOR-CARU	17						42			
mean		1,138	(1 276)	6	49	45		60	37	3
SE		126	(141)	1	4	4		—	—	—
range		468-2,047	(525-2 295)	1-15	28-85	10-70		—	—	—
POTR/SYOR-POPR	5						15			
mean		914	(1 025)	5	45	50		41	57	2
SE		103	(115)	1	8	8		—	—	—
range		704-1,288	(789-1 444)	1-8	17-63	30-80		—	—	—
POTR/SYOR-RUOC	5						8			
mean		1,248	(1 399)	8	71	21		30	38	32
SE		230	(258)	6	9	5		—	—	—
range		753-2,035	(844-2 281)	1-30	40-90	8-33		—	—	—
POTR/ARTR-FEID	0						2			
mean		—	—	—	—	—		47	53	0
SE		—	—	—	—	—		—	—	—
range		—	—	—	—	—		—	—	—
POTR/GEVI	1						5			
mean		797	(893)	1	74	25		47	48	5
SE		—	—	—	—	—		—	—	—
range		—	—	—	—	—		—	—	—
POTR/WYAM	2						7			
mean		1,169	(1 310)	1	90	9		30	33	37
SE		121	(136)	0	6	6		—	—	—
range		1,048-1,289	(1 175-1 445)	1-1	84-95	4-15		—	—	—
POTR/CARU	12						35			
mean		867	(972)	2	33	65		70	30	0
SE		70	(78)	1	6	6		—	—	—
range		469-1,270	(526-1 424)	0-10	4-74	25-95		—	—	—
POTR/CARU-POPR	5						13			
mean		768	(861)	2	42	56		55	44	1
SE		139	(156)	1	9	8		—	—	—
range		446-1,228	(500-1 377)	1-5	20-74	25-75		—	—	—
POTR/POPR	4						12			
mean		859	(963)	1	38	61		33	64	3
SE		81	(91)	0	6	6		—	—	—
range		649-1,023	(728-1 147)	1-1	25-54	45-74		—	—	—
POTR/RUOC	3						4			
mean		794	(890)	2	81	17		48	35	17
SE		218	(244)	1	4	4		—	—	—
range		482-1,214	(540-1 361)	1-3	75-90	8-22		—	—	—
All stands	114									
mean		937	(1 050)	13	45	42				
SE		34	(38)	2	2	2				
range		244-2,047	(274-2 295)	0-80	4-95	3-95				

[1]Number of intensively sampled stands used to compute production.
[2]Total number of stands used to determine forage suitability.

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Mueggler, Walter F.; Campbell, Robert B., Jr. Aspen community types on the Caribou and Targhee National Forests in southeastern Idaho. Res. Pap. INT-294. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 32 p.

A system is presented for classifying aspen-dominated vegetational communities on the Caribou and Targhee National Forests in southeastern Idaho. A diagnostic key utilizing indicator plant species is provided for field identification of 23 community types. Tables are provided for detailed comparison of vegetational composition, productivity, and probable successional status.

KEYWORDS: aspen forests, community types, vegetation classification, Idaho

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Ecological Adaptations in Douglas-fir Populations. II. Western Montana

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THE AUTHOR

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RESEARCH SUMMARY

Seedlings from 50 populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) from Montana west of the Continental Divide were compared in nursery, laboratory, and shadehouse studies. Analyses of variance indicated significant differences among populations in six traits: bud burst, bud set, 3-year height, growth rate, cold injury, and flushing periods during the first or third growing season. Most traits were highly intercorrelated; thus, populations that expressed a high growth potential also set buds late, flushed twice, grew at a rapid rate, but were most severly injured by freezing. Consequently, adaptation of populations for numerous traits is viewed as a balance between selection of high growth potential in relatively mild environments and selection for cold hardiness in severe environments.

Multiple regression analyses related genetic differentation of populations to geographic and ecologic conditions of the seed source. The regression model that best fit the data described adaptive variation according to two physiographic zones, elevation within each zone, and latitude within zones. Patterns of adaptive differentiation were used to develop seed transfer guidelines for reforestation and tree improvement.

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Ecological Adaptations in Douglas-fir Populations. II. Western Montana

NTRODUCTION

Genetic differentiation among populations of Douglas- (*Pseudotsuga menziesii*) is closely related to the nvironment. In the coastal variety (*Pseudotsuga enziesii* var. *menziesii*), genetic variation within a single ainage was clearly related to elevation and topographic tting (Campbell 1979; Campbell and Franklin 1981). For e Rocky Mountain variety (*Pseudotsuga menziesii* var. *auca*), the growth potential and cold hardiness of pulations depends on geographic origin: populations m northern Idaho tend to be faster growing and less irdy than those from western Montana which, in turn, e faster growing and less hardy than populations from uthern Idaho (Rehfeldt 1979b). Within northern Idaho one, differences among populations are closely related the elevation, latitude, and longitude at the seed origin ehfeldt 1979a).

The main objective of the present study is to describe tterns of genetic variation among Douglas-fir popu- ions from Montana west of the Continental Divide (fig. The study excludes the extreme northwest portion of e area which presents patterns of environmental varia- n (Pfister and others 1977) and genetic differentiation ehfeldt 1979a,b) that are similar to those of northern aho. Patterns of variation will be used to: (1) develop idelines for the transfer of seeds that should limit aladaptation in reforestation, and (2) delineate the eeding zones within which genetic gains from tree im- vement will accrue.

Western Montana (fig. 1), a region of diverse montane vironments, is separated from contiguous areas by the ntinental Divide on the east and south, the Cabinet d Bitterroot Mountains on the west, and a political undary to the north. Within this region, climatic, physio- aphic and ecologic conditions follow a well-described ttern from the west and northwest toward the Conti- ntal Divide (Pfister and others 1977). Remnants of a maritime climate in the northwest are gradually lost as the general climate becomes continental. The elevation of valley floors increases from about 2,000 ft to 4,000 ft (600 m to 1 200 m). Concomitant changes in the frequency of particular habitat types largely reflect a gradual decrease in species most common in moist environments. Finally, effects of topography are superimposed on general environmental trends to produce the extreme environmental heterogeneity that characterizes the region. And within this region, Douglas-fir occupies a range of sites from the relatively warm, near lower timberline, to relatively cold subalpine environments above 6,500 ft (2 000 m) elevation (Pfister and others 1977).

MATERIALS AND METHODS

To assess population differentiation, co[illegible] collected from several squirrel caches in each of 50 [illegible]ations from western Montana (fig. 1). Populations, selected to represent the ecological amplitude of the species within the region, differed in elevation by as much as 4,300 ft (1 300 m); and represented habitats (Pfister and others 1977) as dry and warm as the *Pseudotsuga menziesii/Agropyron spicatum*, as cool as the *Abies lasiocarpa/Vaccin* [illegible] *plicata/Clintonia uniflora* habitat types. In addition to populations from western Montana, some populations [illegible] adjacent geographic provinces (fig. 1) were included [illegible]es of (1) growth potential an[illegible] (2) cold hardiness, and (3) patterns of first-year shoot [illegible]ation. Data from all studies were used to as[illegible]ation.

Growth and Phenology

[illegible] from 54 populations were grown for 1 [illegible] plastic tubes (4 in^3, 65 cm^3) in a shadehous[illegible] Idaho. In autumn of the first gro[illegible]

were transplanted into six environments (table 1) on the Priest River Experimental Forest in northern Idaho (fig. 1). While two plantings were in a nursery, four were established on various forest sites. Although plantings on these four sites were made in the residual soil, rocks, roots, and competing vegetation had been removed before tilling. All plantings received natural precipitation. Twelve seedlings from each population were planted in row plots in each of two replicates in all environments. Rows were separated by 4 in (10 cm); 3 in (8 cm) separated seedlings within rows.

Growth potential and phenology of seedlings was assessed from the following scores and measurements obtained for each population in all replicates:

1. Bud burst: the day after April 1 by which 50 percent of the seedlings had burst terminal buds during the third growing season.
2. Bud set: the week by which 50 percent of the seedlings had set terminal buds during the third growing season.
3. Two flushes: the proportion of seedlings that flushed more than once during the third growing season.
4. Height: average seedling height after 3 years.
5. Growth rate: deviation from regression of 3-year height on 2-year height; an index to the rate of growth from a constant height at age 2.

Population differentiation was assessed from the model of random effects:

$$Y_{ijk} = \mu + p_i + e_j + r_{jk} + g_{ij} + d_{ijk}$$

where Y_{ijk} *is the performance of population i* in replicate k of environment j; μ is the overall mean; p_i is the effect of population i; e_j *is the effect of environment j*; g_{ij} is the interaction of population i in environment j; and d_{ijk} is the residual variation. While most analyses were made on the original variables, proportions were transformed to arcsin $\sqrt{X}$ and bud set was transformed to $\sqrt{X + 1/2}$.

Cold Hardiness

Tolerance to freezing was studied with 50 seedlings from each of 58 populations that had been growing for 2 years in plastic containers (9 in^3; 150 cm^3) in a shadehouse at Moscow, Idaho. In general accordance with procedures outlined by Levitt (1972), freezing tests were made to assess hardiness of each population in mid-September when first autumnal frosts can be expected. This single date was chosen because northern Idaho populations expressed greatest differentiation in cold hardiness after bud set but prior to the first frost of autumn and because previous tests indicated that the ranking of populations according to hardiness did not change in subsequent sampling dates (Rehfeldt 1979d).

Terminal shoots from each of the 58 populations were cut and arranged into 5 sets of 10 shoots (3 in; 8 cm long). Each set was moistened, packaged in a plastic bag, and stored overnight at 37° F (3° C). The following morning, plastic bags were suspended in a freezing chamber equipped with two fans for providing circulation. One set of shoots from each population was frozen at the rate of 9° F (5° C)/h to one of five test temperatures between 7° F and 0° F (−14° C and −18° C). While within the plastic bags, shoots were removed from the freezer when remote temperature sensors indicated that internal air temperatures had reached desired levels, were thawed for 24 h at 37° F (3° C), and were placed on a shaded greenhouse bench. After 2 days, the presence or absence of injury to each shoot was scored by discoloration of leaves. For each population, the number of seedlings exhibiting leaf injury was recorded for each test temperature.

Differentiation of populations was assessed by an analysis of variance of random effects on the percentage of shoots of each population exhibiting injury at each tes temperature:

$$Y_{ij} = \mu + p_i + t_j + g_{ij} + e$$

where Y_{ij} is the percentage of twigs injured from population i at temperature j; μ is the overall mean; p_i is the effect of population i; t_j is the effect of temperature j; g_{ij} *is the interaction of population i* at temperature j; and e is the theoretical variance of an observation in a binomial distribution (Steele and Torrie 1960). Percentage were transformed to arcsin $\sqrt{X}$ before analyses were made.

Patterns of First-Year Growth

Douglas-fir seedlings exhibit contrasting patterns of growth during the first growing season (Rehfeldt 1979c). For essentially all seedlings from western Montana. a terminal bud is set about 1 month after germination. But, only a portion of these seedlings burst bud and resume growth in late July or August. To test for differences among Montana populations in patterns of first-year elongation, 30 to 40 seedlings from 50 populations were grown in plastic containers (4 in^3; 65 cm^3) in each of four replicates. The proportion of seedlings that exhibited a single growth period was recorded for each population in all replicates. Proportions were transformed (arcsin $\sqrt{X}$) before statistical analyses that followed a model identica to that used for freezing tolerance.

Patterns of Variation

Data from the separate studies were used to assess differentiation in relation to geographic and ecologic criteria of the seed sources according to the general model:

$$Y_i = b_0 + b_1 X_{i1} + b_2 X_{i2} \ldots + b_n X_{in}$$

where Y_i is the mean performance of population i; b's are regression coefficients; and X's are various independent variables (table 2). Qualitative independent variables were included in the model by fitting constants, values of zero or one (Draper and Smith 1966). Of the independent variables, habitat types included five major series on which Douglas-fir is common (Pfister and others 1977); Idaho departure is distance from the State line; and northwest departure is an imaginary grid distance from northwest to southwest through western Montana.

Table 1.—Trait means according to environment

Environment	Bud burst	Bud set	Two flushes	Height	Growth rate
			Trait		
Nursery shade, 730 m	33 4	2 9	[illegible]	[illegible]	[illegible]
Nursery sun 730 m	31 7	[illegible]	[illegible]	[illegible]	[illegible]
Reservoir, 790 m	31 4	[illegible]	[illegible]	[illegible]	[illegible]
M-2 Road, 1 [illegible]	35 8	[illegible]	[illegible]	[illegible]	[illegible]
North Ridge west, 1 520 [illegible]	60 8	[illegible]	[illegible]	12 6	[illegible]
North Ridge east, 1 580 [illegible]	66 3	[illegible]	[illegible]	10 6	[illegible]

[illegible]

regions showing location [illegible]

For all regression models, residuals from regression were examined visually in relation to observed and predicted values to assess homogeniety of error variances and the fit of data to regression models (Draper and Smith 1966). Thus, seven regression models were fitted to the data (table 2). Adequacy of a model was judged according to the goodness of fit (R^2), residual variance ($s_{y \bullet x}$), and geographic or ecologic patterns displayed by residuals.

RESULTS

Six environments exerted considerable influence on the growth and phenology of seedlings (tables 1 and 3). Most of this influence was directly related to elevation. As compared to seedlings growing in the nursery at low elevation, seedlings growing at high elevations on North Ridge burst bud about 4 weeks later, set buds about 6 weeks later, grew at a slower rate (negative deviation from regression), and, consequently, were about 3 in (7.5 cm) smaller. Only the proportion of seedlings that flushed twice seemed to be independent of elevation, but perhaps not independent of shade. The two environments with the lowest proportion of seedlings that flushed twice included the nursery that received 50 percent shade and M-2 Roa that received afternoon shade.

Populations differed greatly in phenology and growth potential (table 3). In the average environment, populations from western Montana differed by as much as 6 days in bud burst, 6.2 weeks in bud set, 53 percent seedlings that flushed twice, 2.7 in (7 cm) in height, and 1.2 in (3 cm) in growth rate (third-year growth from a constant height at age 2). In addition, populations performed essentially the same in all environments. Interactions of genotype and environment were detected for only bud burst and height. While accounting for little variance, these interactions, like those detected for nort Idaho populations (Rehfeldt 1979a), resulted from mean differences not associated with changes in the ranking populations.

Laboratory studies of freezing tolerance revealed significant differences among 58 populations (table 4A). Even though test temperatures spanned only 9° F (5° C) percentage of injury to all twigs ranged from 19 percent 7° F (−14° C) to 75 percent at 0° F (−18° C). Across th range of temperatures, mean injury to populations from western Montana ranged from 16 to 69 percent.

Shadehouse studies of the pattern of first-year elongation revealed significant differences among popu tions in the proportion of seedlings that exhibited a sing growth period (table 4B). Mean values for Montana popu lations ranged from 24 to 74 percent.

Table 2.—Independent variables included in various models for relating population differentiation to geographic and ecologic conditions of the seed source

Independent variable	Variables included in model: 1	2	3	4	5	6	7
Latitude	x						
Longitude	x						
Habitat types	x						
Elevation	x	x	x		x		
Northwest departure		x					
Idaho departure		x					
Three major drainages			x	x			
Elevation within drainages				x			
East and west physiographic zones					x	x	x
Elevation within zones						x	x
Northwest departure in zones					x	x	
Latitude in zones							x

Table 4.—Analyses of variance for freezing injury (A) and one period of growth (B)

Source of variance	Degrees of freedom	Mean square
A. Freezing injury		
Temperatures	4	6.2206*
Populations	57	.1280*
Temperature x Population	228	.0424
Sampling error[1]	—	.0250
B. One period of growth		
Replication	3	0.0478*
Populations	49	.0499*
Replication x Population	147	.0155
Sampling error[1]	—	.0148

[1]Theoretical variance of a binomial distribution.
**Statistical significance at the 0.01 level of probability.

Table 3.—Mean squares from analyses of variance for population performance in nursery environments

Source of variation	Degrees of freedom	Bud burst	Bud set	Two flushes	Height	Growth
Environments	5	27,290.59**	38.400**	1.9907**	1097.39**	84.64
Reps/environment	6	10.22**	1.079**	0.2538**	23.25**	21.33
Populations	53	20.54**	1.499**	.3116**	95.51**	6.43
Pops. x environment	265	1.78	0.312*	.0433	5.36**	1.53
Residual	318	1.92	.247	.0447	2.07	1.57

[1]Deviation from regression of 3-year height on 2-year height.
*Significant at the 0.01 level of probability.
*Significant at the 0.05 level of probability.

Variation in growth, phenology, cold hardiness, and first-year flushing of western Montana populations formed an intercorrelated network of traits to which only bud burst was unrelated (table 5). This network, like that for northern Idaho populations (Rehfeldt 1979a), seems keyed to adaptation to the cold. Populations that set buds early were also characterized by a low proportion of seedlings that flushed twice, a low growth rate, a short height, but a high tolerance to freezing.

Because of strong intercorrelations, results of the series of regression analyses (table 6) showed similar patterns for all traits. In general, the sequence of regression models shows an increase in values of R^2 and a decrease in residual variances. Regression model 1 (table 2) indicated that (1) genetic variation was related to elevation; (2) geographic patterns of variation followed a grid that was oblique to latitude and longitude; and (3) habitat types were related to neither dependent nor independent variables. A lack of association between habitat types and genetic variation in western Montana corresponds with results for Douglas-fir populations from northern Idaho (Rehfeldt 1979a) and for *Pinus ponderosa* from southern Idaho (Rehfeldt 1980).

Residuals from model 2 suggested that geogr[illegible] patterns of variation were discontinuous at 40 to 60 [illegible] to 100 km) from the Idaho state line, a boundary that [illegible] sts of the Cabinet and Bit[illegible] Mountains. Populations from the Bitterroot [illegible] Clark Fork drainages differed from eastern po[illegible] nd elevations. This discontinuous pattern of variation was incor[illegible] models 3 to 6, whic[illegible] that best represented the data. R[illegible] model 7 generally produced the highest fit a[illegible] ice. But also, [illegible] obvious geographic or ecologic patterns.

In model 7, genetic variation is described according to [illegible] elevation within each zone, and latitude within zones. The [illegible] graphic zone includes the Bitterroot and west Clark Fork drainages; the eastern zone is composed of the Flathead and east Clark Fork drai[illegible] generated by predicting population performance (Y) from multiple regre[illegible]

Table 5.—Matrix of simple correlation coefficients a[illegible]

	BS	TWF	H	GR	[illegible]	FZ
Bud burst (BB)	-0.13	-0.22	0.12	0.02	0.21	0.05
Bud set (BS)		91*	72*	49**	-.45	49*
Two flushes (TWF)			61*	[illegible]	[illegible]	40*
Height (H)				25	[illegible]	[illegible]
Growth rate (GR)					[illegible]	[illegible]
One period (OP)						[illegible]
Freezing injury (FZ)						

*Statistical significance at the 0.05 level of probability
**Statistical significance at the 0.01 level of probability

Table 6.—Results of several multiple regression models (table 2) for relating genetic variation to geographic and ecologic conditions of the seed source

Regression model	Bud burst		Bud set		Two flushes		H[illegible]		Growth rate		One period		Cold hardiness	
	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$	R^2	$s_{y \cdot x}$
1	0.26**	1.021	0.30	0.2435	0.32**	0.1044	0.60**	1.138	0.11	0.5500	0.12	0.0980	0.23**	[illegible]
2	.30**	.991	.38**	.2299	.38**	.1003	61**	1.127	10	5534	13	[illegible]	[illegible]	[illegible]
3	.23	1.039	42**	.2225	.45**	.0939	58**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31**	[illegible]
4	.31**	1.011	.48**	.2146	.50**	0916	59**	[illegible]	27*	[illegible]	17	[illegible]	37**	1121
5	.28**	1.011	.46**	.2166	.49**	0917	68**	1.031	[illegible]	5355	[illegible]	0984	34**	[illegible]
6	.32**	1.005	.49**	.2126	.51**	0909	.70**	1.006	21	5300	[illegible]	0970	35**	[illegible]
7	.32**	1.003	.52**	.2071	.52**	0900	72**	978	[illegible]	[illegible]	[illegible]	0964	[illegible]	[illegible]

*Statistical significance at the 0.05 level of probability
**Statistical significance at the 0.01 level of probability

intercorrelations among dependent variables, similar results of regression models (fig. 2) were expected for bud set, two flushes, height, growth rate, and freezing injury. But the same model was also effective for bud burst largely because of strong effects of latitude and elevation within the western zone. Similarly, elevation within the western zone was the only independent variable significantly associated with the proportion of seedlings that displayed one growth period. Consequently, results of the multiple regression for the latter variable are presented even though the entire model was not significant.

The regression models generally depict: (1) decreasing growth potential and increasing hardiness of populations in association with increasing elevation of the seed origin; (2) greater growth potential but lesser hardiness of populations in the western zone than in the eastern zone; (3) effects of elevation on genetic differentiation that are generally stronger in the western zone than in the eastern zone; and (4) effects of latitude in the west that are the reverse of those in the east. Thus, at a constant elevation, hardiness of populations increases while growth potential decreases northward through the western zone and then southward through the eastern zone. Thereby, genetic differentiation in populations from different physiographic zones is greater in the southern portion of western Montana that in the northern portion.

Finally, since nursery and laboratory studies included a few populations from geographic regions adjacent to western Montana, geographic variation can be assessed further. As noted previously (Wright and others 1971; Rehfeldt 1979b), populations from northern Idaho expres greater growth potential but lesser hardiness than western Montana populations from comparable elevatio (table 7). In addition, populations from the severe environments of central Montana and central Idaho express an extremely low growth potential but high hardiness.

DISCUSSION

By illustrating strong geographic and ecologic patterr in genetic differentiation, the present results further exemplify intense physiological attunement of Douglas-f populations to their environment. Adaptation of populations is readily interpreted as a balance between selecti of high growth potential in mild environments and selec tion for cold hardiness in severe environments. Montana populations, like those from northern Idaho, were readily differentiated by a network of intercorrelated traits: populations of high growth potential were tall, set buds late, grew at a rapid rate, expressed pronounced tenden cies for multiple flushing, but suffered the most injury from freezing. Accordingly, as compared to populations from western Montana, those from northern Idaho expressed adaptations to a milder climate; and those from southern Idaho and central Montana expressed adaptations to a more severe climate.

In addition, patterns of genetic variation depicted by multiple regression models seem uniquely suited to the climate and physiography of western Montana. A weste physiographic zone contained populations of higher

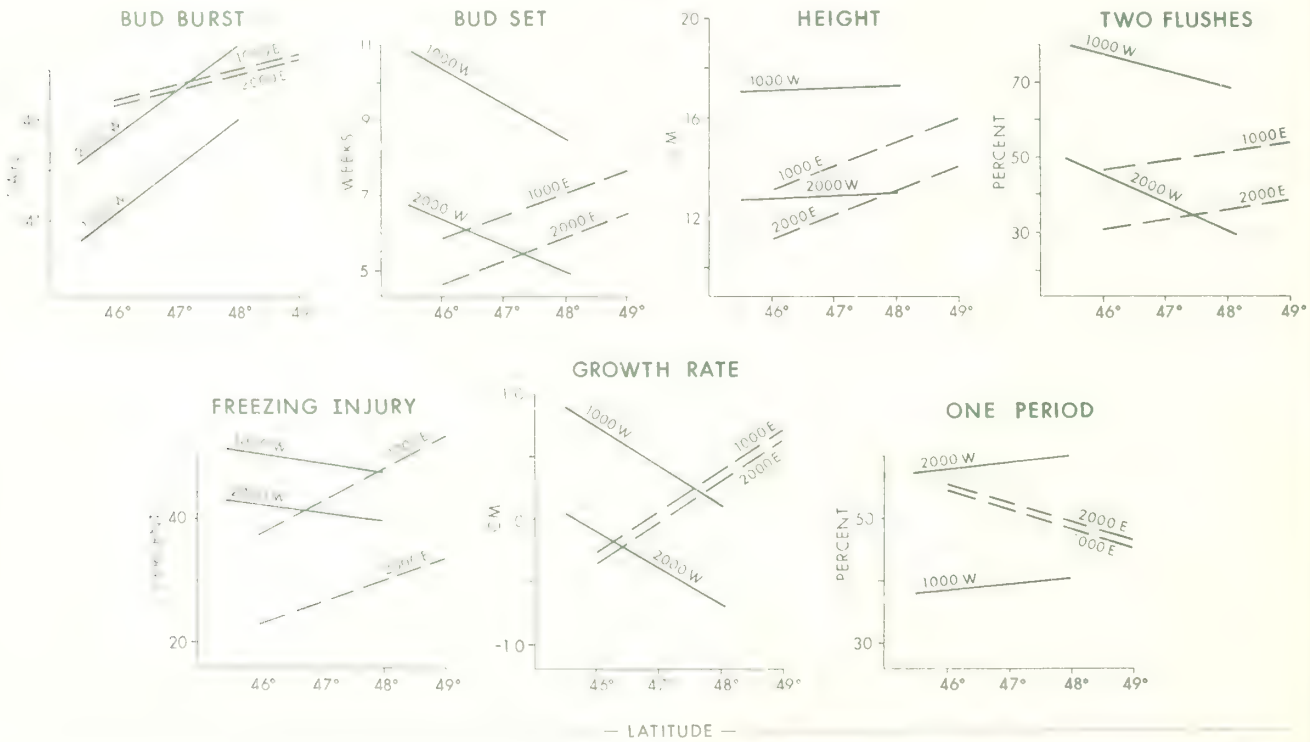

Figure 2.—Results of multiple regression model 7 (table 2) depicting the predicted performance (ordinate) in relation to the latitude (abscissa), geographic zone (E = eastern, W = western), and the elevation (1 000 m or 2 000 m) of the seed source.

Table 7.—Average deviation in performance of populations from [illegible] populations at comparable elevations

Geographic area	Sample populations	Bud burst	Bud set	Two flushes	Height	Growth rate	One period	Freezing injury
	Number	*Days*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Northern Idaho	[illegible]	0.6	1.9	6.3	5.6	[illegible]	[illegible]	[illegible]
Central Idaho	3	2.2	[illegible]	[illegible]	[illegible]	[illegible]	5.2	[illegible]
Central Montana	1	-2.0	[illegible]	[illegible]	[illegible]	[illegible]	11.9	[illegible]

growth potential and lesser hardiness than populations from similar elevations and latitudes in an eastern zone. The boundary between eastern and western zones g[illegible]ally follows the crest of the Sapphire Mountains [illegible] separate the Bitterroot Drainage from the eastern [illegible] Fork, and includes the Jocko Range and the Cal[illegible] Mountains, which separate the Flathead Drainage from the western Clark Fork (fig. 1). Moreover, a climate with considerable maritime influence in the west and northwest becomes decidedly more continental as the Continental Divide is approached; this climatic pattern is reflected in the distribution of plant communities (Pfister and others 1977; Arno 1979). Consequently, it is appropriate for Douglas-fir populations from the western zone to express adaptations to a milder climate than populations from the eastern zone.

For genetic variation to be related to elevation of the seed source is not surprising: growing seasons generally decrease with increasing altitude; an intercorrelated network of traits is keyed to adaptations to the cold; and for both Oregon (Campbell and Sorensen 1978; Campbell 1979) and northern Idaho (Rehfeldt 1979a) populations, genetic variation has been related to elevation. However, the strength of the relationship between differentiation and elevation depended on the physiographic zone. For instance, in the western zone, 3-year height of populations decreased by about 26 percent over an elevational difference among seed sources of 3,280 ft (1 000 m). The corresponding decrease for the eastern zone amount[illegible] about 14 percent while that for the northern Idaho populations was about 28 percent (Rehfeldt 1979a). T[illegible] in areas where climatic gradients in altitude should be the steepest, the strongest associations between diff[illegible]tion and elevation were apparent. Near the Continental Divide, the difference in environmental severity be[illegible] high and low elevations, judged by the distribut[illegible] habitat types (Pfister and others 1976), is the [illegible] clinal gradients are relatively flat.

In the Northern Hemisphere, populations of [illegible] plants from southern latitudes generally show h[illegible] growth rates and lesser hardiness than populations [illegible] northern latitudes. Thus, differentiation among D[illegible] populations in northern Idaho (Rehfeldt 1979a) and in Montana's western physiographic zone follow[illegible] pected trend even though the latitudinal [illegible] small (3.5 degrees). However, patter[illegible] entiation in the eastern physiograph[illegible] contrasting pattern: northern populations were of the highest growth potential and lowest hard[illegible] patterns of latitudinal differentiation in the east[illegible] are readily interpreted by climatic patter[illegible] the unique physiognomy of the [illegible] maritime climatic influence decrease from the [illegible] toward the southwest, but also, elevation of vall[illegible] increa[illegible] much of the region drained by the eastern Clark Fork represents an ecotone between the relatively mo[illegible] vironment to the west and north and the severely [illegible] dry habitats to the east. Thus, it is appropriate for (1) northern populations of the east[illegible] growth potential and lower hardiness than south[illegible] lations, and (2) for genet[illegible] tions from diff[illegible] portion of western Montana than in [illegible]

Regression models accounted for only a portion of the variance among populations. However, a perfect fit of regression models to data cannot be expected even if all [illegible]nt independent variables could be assessed. High levels of genetic variability exist within popul[illegible] regardless of geographic origin (Campbell 1979, Rehfeldt 1979b). Natural sampli[illegible] pressures that vary in time and space can a[illegible] random patterns of differentiat[illegible] [illegible]ldt 1974). Moreover, experimental errors, including sampling errors, can account [illegible] variance. Perhaps it is surprising that regress[illegible] accounted for as much as 72 percent of the var[illegible]

Patterns of adaptive differentiat[illegible] for which maladaptation of planted trees is minimal. As proposed previously (Rehfeldt 1979a), *lsd*(0.2) [illegible] *lsd*(0.2) = least significant [illegible] at the 80 [illegible] popul[illegible] the Bitt[illegible] the Fl[illegible] ± 30 miles (50 [illegible] 1,050 ft [illegible] (75 km [illegible]

Table 8.—Geographic and elevational distances associated with mean differences among seed sources that correspond to a significance level of 80 percent

Trait	Western zone			Eastern zone		
	Elevation	Latitude		Elevation	Latitude	
	Meters	*Degrees*	*km*	*Meters*	*Degrees*	*km*
Bud burst	474	0.8	94	2 567	2.5	296
Bud set	422	1.9	222	1 195	2.3	266
Two flushes	359	1.5	171	708	3.8	448
Height	278	11.4	1 337	656	1.3	149
Growth rate	782	2.0	234	6 578	2.0	229
One period	586	11.5	1 350	9 928	3.5	414
Freezing injury	1 924	7.4	866	1 001	3.9	460

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Rehfeldt, Gerald E. Ecological adaptations in Douglas-fir populations. II. Western Montana. Res. Pap. INT-295. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 8 p.

Populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) from Montana west of the Continental Divide were compared in common environments. Differentiation was observed for six variables reflecting growth potential, phenology and cold hardiness. Adaptation of populations for numerous traits is viewed as a balance between selection of high growth potential in relatively mild environments and selection for cold hardiness in severe environments. Adaptive variation is described according to two physiographic zones, elevation within each zone, and latitude within zones.

KEYWORDS: Douglas-fir, ecological genetics, growth potential, cold hardiness, phenology, tree improvement

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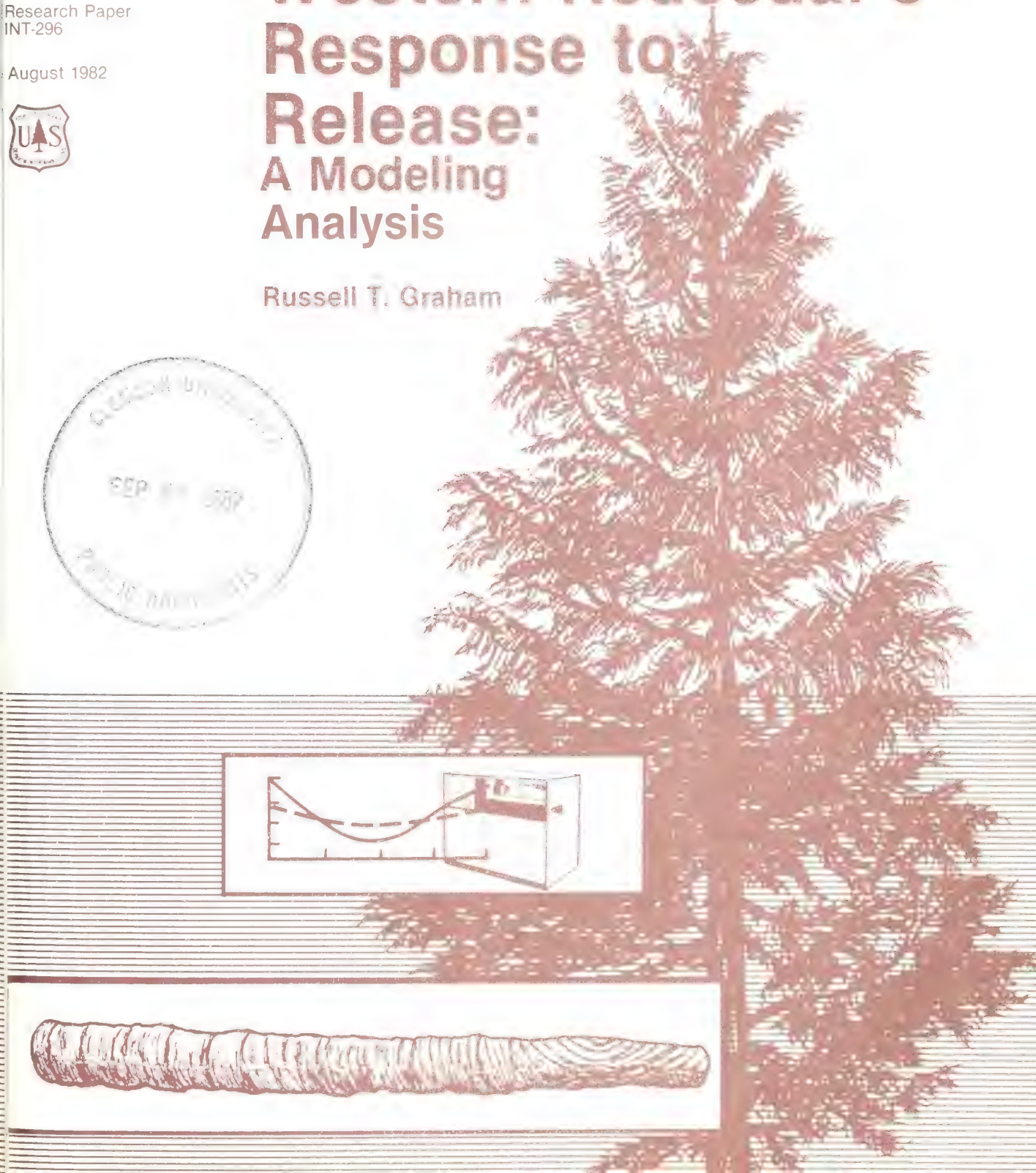
Influence of Tree and Site Factors On Western Redcedar's Response to Release:

A Modeling Analysis

Russell T. Graham



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RESEARCH SUMMARY

Western redcedar is one of the most important commercial species in the Northern Rocky Mountains. The species usually responds well to release, but the response often varies tremendously, depending on site and tree characteristics. Therefore, this study was implemented to identify the site, stand, and tree characteristics associated with the release response of western redcedar. Because no untreated stands were available to compare to the treated stands, a diameter increment model was developed and used in the analysis.

Western redcedar appeared to best respond to release from overhead and surrounding competition on northerly aspects. In contrast, the poorest response to release occurred on southerly aspects. After release the species showed the best growth in the *Thuja plicata/Pachistima myrsinites* habitat type and the poorest growth on the *Tsuga heterophylla/Pachistima myrsinites* habitat type.

The larger the tree was at the time of release the better it responded to release. In contrast, the older the tree was at the time of release the poorer the response it had to the treatment.

Soil characteristics were also associated with the release response of western redcedar. Trees growing on soils with high pH's showed the poorest responses to release. Also, trees growing on soils with large amounts of total nitrogen, iron, and copper showed poorer responses to release, whereas soils with larger amounts of nitrate, ammonium, sulfate, and potassium supported the trees that showed the better growth rates after release.

In addition, foliage characteristics of western redcedar were associated with the diameter increment response of the species to release. Trees with the larger amounts of foliar phosphorus and manganese had better growth rates after release than trees with smaller amounts of these nutrients. Trees with larger amounts of foliar sulfur, iron, sodium, and potassium had poorer growth rates after release compared to trees with smaller amounts of these nutrients.

Foliage color was related to the response of western redcedar to release. Trees with green-yellow colored foliage showed a better response to release than trees with greenish green-yellow foliage. Also, foliage color indicated the nutrient content of the foliage; mean nutrient content differed among 12 different colors.

The results of this study show that western redcedar will respond favorably to release from overhead and surrounding competition. The site and tree characteristics that are related to the release response may be used to help design treatment alternatives for releasing stands of western redcedar.

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Influence of Tree and Site Factors On Western Redcedar's Response to Release:

A Modeling Analysis

Russell T. Graham

TRODUCTION

Vestern redcedar (*Thuja plicata* Donn.), occupying proximately 330,000 acres (133 500 hectares), with a al live volume of 10 billion board feet (Bolsinger 79), is one of the more important commercial species the Northern Rocky Mountains. The natural durabil- and good wood working properties of western red- lar make it desirable for use by the building indus- . Because of its natural resistance to decay, western cedar is ideally suited for use as posts, poles, shakes, ngles, and for siding. In recent years the demand for it products and lumber has caused large price in- ases for western redcedar. In western Washington d northwestern Oregon, western redcedar log prices reased from $57.30 per thousand board feet in 1965 $320.80 per thousand board feet in 1977 (Bolsinger 79) and continued to show an increase in current rkets. Of the estimated 950 million board feet of stern redcedar harvested between 197[illegible] percent consisted of trees that were 21 inches (53.3) diameter at breast height and larger (Bolsinger 79).

Western redcedar in the Northern Rocky Mountains ws on many different sites where it occ[illegible] nax or accidental species on five different habitat es (Daubenmire and Daubenmire 1968; Steele and ers 1976). Western redcedar is the major climax ecies on the *Thuja plicata/Pachistima myrsinites*, *uja plicata/Athyrium filix-foemina*, and *Thuja ata/Oplopanax horridium* habitat types. On the *uga heterophyla/Pachistima myrsinites* habitat [illegible] *tima myrsinites* habitat type.

[illegible] *dentalis* Nutt.), grand fir (*Abies grandis* [Dougl.] Lindl.), [illegible] Rocky Mountains. It is capable of reproducing and [illegible] stands.

[illegible] Because western redcedar is shade tolerant, these understory trees may be multiaged and diverse in size. [illegible] with the diameter increment responses of western red cedar to release from overhead and surrounding compe- tition

THE SITE, STAND, AND TREE CHARACTERISTICS ASSOCIATED WITH THE RELEASE RESPONSE OF WESTERN REDCEDAR

Literature Review

Growth of shade-tolerant tree species increases in response to the removal of overhead and surrounding competition. Overstory removal has been found effective in increasing growth rates of shade-tolerant coniferous understory species (Leaphart and Foiles 1972; Koenigs 1969; Ferguson and Adams 1979; Seidel 1977). Likewise, understories of tolerant deciduous trees can be released successfully (Johnson 1975; Carvell 1967; Sander and others 1976). Growth response after overstory removal is often delayed one or more years as the understory becomes acclimated to its new environment (Herring 1977; Herring and Ethridge 1976). Shade-tolerant species are also capable of increased growth rates after intermediate stand treatments such as cleanings and thinnings (Deitschman and Pfister 1973; Berry 1968).

Tree characteristics such as diameter, height, crown condition, rooting habit, and age are related to the growth performance of a tree after release. Larger diameter tolerant trees usually show better growth response after release than smaller diameter trees (Leaphart and Foiles 1972; Herring and Ethridge 1976; Johnson 1975). Shade-tolerant trees with extensive symmetrical root systems and little root mortality respond well to release (Leaphart and Grismer 1974; Eis 1974). The response of tolerant species to release is related to tree age in some species such as grand fir (*Abies grandis* [Dougl.] Lindl.) (Ferguson and Adams 1979); however, age is not associated with the response of other species such as subalpine fir (*Abies lasiocarpa* [Hook.] Nutt) (Herring 1977, Crossley 1976).

Site characteristics are important in governing the amount of growth that occurs after a tolerant species is released. Most tolerant coniferous species respond best to release from competition on cool, moist sites (Ferguson and Adams 1979; Herring 1977; Herring and Ethridge 1976), as do many deciduous trees (Johnson 1975).

Release cuttings can increase the chance of disease in the residual trees. When the overstory was removed and the residual western redcedar stand thinned in a northern Idaho site, 69 percent of the trees were infected by root rotting organisms, while in the untreated stand only 36 percent of the trees were infected (Koenigs 1969). Similarly, Berry (1968) reported high mortality caused by root diseases in thinned stands of white spruce (*Picea glauca* [Moench] Voss). Release cuttings in stands of western hemlock can increase root diseases by damaging residual trees thus providing entry points for disease causing organisms, and also by creating stumps that can be colonized by root pathogens (Wallis and Morrison 1975).

The leaves of shade-tolerant species are adapted to low light conditions and must change or be replaced when exposed to increased light. Shade-tolerant beech (*Fagus grandifolia* Ehrh.) leaves are efficient in dim light with leaf stomata opening rapidly in response low light levels (Woods and Turner 1971). This allo the species to take advantage of short periods of lig for photosynthesis even though the photosynthetic may be very low (Loach 1967). In addition, tolerant species have low respiration rates that help them su vive in shaded conditions (Loach 1967). Trees with leaves adapted to shaded environments often die or develop parch blight when suddenly exposed to ope light conditions (Boyce 1961). The death or damage trees released from competition can be related to th inability of the foliage to adapt or change to the new light conditions. Depending upon the amount of exp sure, many shade leaves on a tree will drop when a release cutting occurs, as others adapt to the new li conditions (Tucker and Emmingham 1977). Leaves veloping on released shade-grown trees usually hav two rows of palisade mesophyll cells compared to o row on the shade-grown leaves (Aussenac 1973). Shade-grown leaves that do not drop will often incr in thickness and in weight-to-length ratios, thus bec ing more adapted to their new environment (Tucke and Emmingham 1977).

Methods

DATA COLLECTION

A survey approach was used to study the respons western redcedar diameter growth at breast height (d.b.h.), to various kinds of release from competitior including thinning, weeding, cleaning, and overstor removal. To assure that a response could be measu stands chosen for sampling had a minimum of 10 y of tree growth since the release treatment. Each sta selected was uniform in slope, aspect, soil type, and stand history. Fifteen stands meeting the selection criteria were located on various ownerships in easte Washington, northern Idaho, and western Montana during the summer of 1979. No western redcedar stands examined in the central portion of the study area satisfied the stand selection requirements (fig.

Selected stands were described as follows: geogra location, habitat type (Daubenmire and Daubenmire 1968), elevation above sea level, slope, slope confi tion, aspect, and year of release treatment. The hab types represented by the stands in the study includ *Thuja plicata/Pachistima myrsinites* (THPL/PAMY *Thuja plicata/Athyrium filix-foemina* (THPL/ATFI) *Tsuga heterophylla/Pachistima myrsinites* (TSHE/ PAMY), and *Abies lasiocarpa/Pachistima myrsinit* (ABLE/PAMY).

Within each of the 15 stands, two 5-point clusters were established for sampling the trees and lesser vegetation. Each point was the center of a 1/300-ac (0.00133-ha) fixed-radius plot for measurements of up to 5 inches (12.7 cm) d.b.h. and a variable-radiu plot for measurements of trees 5 inches (12.7 cm) d and larger. A basal area factor was used that result selection of four to six trees in the variable radius p For each tree the following were recorded: species, crown class, d.b.h., height, crown ratio (live crown

Figure 1.—Stands used to investigate the growth response of western redcedar to release from competition.

percentage of tree height, and description of any visible damage or injury. From each tree on the variable-radius plots, one increment [illegible] center was extracted at breast height [illegible] side facing the plot center. On each [illegible] the proportion covered by crowns of each shrub species was estimated to the nearest 10 percent and the heights of shrubs were measured to the nearest 1 foot (30.5 cm). Using an occular system developed by Wellner (1979), the percentage of sunlight striking the forest floor was estimated within each stand.

DATA PREPARATION

The 15 stands had a wide variety of characteristics. Mean stand diameters were small, ranging from 0.8 inches (2.0 cm) to 3.0 inches (7.6 cm), and densities varied from 1,296 to 49,289 trees per acre (3,202 to 121,796 per ha) (table 1). The smallest and largest mean stand d.b.h.'s for the 601 growth-sample trees measured on the variable-radius plots, were 6.5 inches (16.5 cm) and 31.8 inches (80.8 cm), respectively (table 2).

Thirty variables both [illegible] 601 growth-sample trees were included in the data as follows:

[illegible] quadrant [illegible]

[illegible] slope, lower slope, valley bottom

[illegible]

10. Sunlight striking forest floor — percent (Wellner 1979)

[illegible]

16. Description of damage or injury to the tree

17. Tree age at breast height based on count of annual growth rings

[illegible]

19. Diameter inside bark for various growth periods computed from annual growth ring measurements [illegible]

20. Basal area percentile — position of tree in stand basal area distribution (BAP)

[illegible]

22. Stand crown competition factor (CCF) (Krajicek [illegible])

23. Stand trees per acre (TPA)

24. Stand basal area (BA) per acre

[illegible]

26. Cluster trees per acre [illegible]

27. Cluster basal area per acre [illegible]

[illegible]

29. Point trees per acre (TPA)

[illegible] data were derived for each point, cluster, and stand, trees per acre (TPA), basal area per acre (BA), and crown competition factor (CCF) (Krajicek and others [illegible] computed: the position of the tree in the basal area dis- [illegible]

The growth-sample trees also provided growth information and age for any period during the life of the [illegible] suring device (Graham 1980a). Diameter in [illegible] ment and for 5, 10, and [illegible] for the years 1975 and [illegible]

Table 1.—Characteristics of released western redcedar stands

Stand No.	Trees tallied	Mean d.b.h.		Mean height		Trees/per		Basal area	
		In	*cm*	*Ft*	*m*	*Acre*	*ha*	*Ft²/acre*	*m²/ha*
1	851	0.8	2.03	3.6	1.10	49,289	121,793	187	17.37
2	253	1.0	2.54	12.0	3.66	7,060	17,445	40	3.72
3	148	1.6	4.06	11.1	3.38	3,763	9,298	55	5.11
4	442	1.4	3.56	9.6	2.93	12,448	30,759	118	10.96
5	314	1.1	2.79	10.1	3.08	8,238	20,356	90	8.36
6	128	1.7	4.32	8.1	2.47	3,320	8,204	51	4.74
7	352	1.9	4.83	21.0	6.40	8,890	21,967	177	16.44
8	770	1.5	3.81	7.2	2.19	20,742	51,253	246	22.85
9	473	1.7	4.32	8.3	2.53	13,100	32,370	217	20.16
10	699	1.2	3.05	6.2	1.89	20,178	49,860	153	14.21
11	322	2.0	5.08	21.4	6.52	8,635	21,337	189	17.56
12	213	2.3	5.84	22.6	6.89	5,563	13,746	153	14.21
13	348	2.5	6.35	24.1	7.35	8,408	20,776	291	27.03
14	52	2.0	5.08	16.2	4.94	1,296	3,202	27	2.51
15	163	3.0	7.62	27.4	8.35	3,649	9,017	180	16.72

Table 2.—Characteristics of growth-sample trees in released western redcedar stands

Stand No.	Number sampled	Mean d.b.h.		Mean height		Mean b.h. age	Mean b.h. at relea
		In	*cm*	*Ft*	*m*	*Yr*	*Yr*
1	35	9.1	23.11	46.9	14.30	69	24
2	22	9.7	24.64	44.0	13.41	64	53
3	25	14.6	37.08	65.9	20.09	65	43
4	33	9.4	23.88	47.6	14.51	78	60
5	28	13.4	24.04	72.7	22.16	77	28
6	22	8.9	22.61	35.1	10.70	36	17
7	59	23.4	59.44	90.4	27.55	94	74
8	81	21.1	53.59	89.8	27.37	94	74
9	54	11.7	29.72	66.6	20.30	57	33
10	39	11.0	27.94	69.9	21.31	89	69
11	46	12.1	30.73	68.3	20.82	147	125
12	36	13.6	34.54	64.8	19.75	71	56
13	69	31.8	80.77	111.0	33.83	84	60
14	14	6.5	16.51	34.3	10.45	72	54
15	38	24.6	62.48	120.2	36.41	169	159

PREDICTION OF NONRELEASED DIAMETER GROWTH

Nonreleased trees were not sampled in this study. Therefore, diameter growth prior to the release treatments was measured from the growth-sample trees and used to construct a regression model to predict nonreleased tree diameter growth. The independent variables that existed at the time of release were evaluated as potential predictors of diameter growth (table 3). To determine the optimum slope and aspect for tree diameter growth without repeated calculations, the sine of the aspect azimuth times the percent slope [Sine (Asp)*Slope] and the cosine of the aspect azimuth times the percent slope [Cos (Asp)*Slope] were used as independent variables (Stage 1976). If either the sine transformation term or the cosine transformation term was significant as an independent variable in predicting diameter growth, they both remained in the regression model.

Table 3.—The prediction model for diameter growth of nonr[illegible]

Nonreleased diameter growth prediction model

$$PGRTH = B(0) + B(1)\,DIA + B(2)\,ELEV + B(3)\,COSINE + B(4)\,SINE + B(5)\,SLOPE + B(6)\,THATFI + B(7)\,THPAMY + B(8)\,TSPAMY$$

where:

PGRTH	= predicted nonreleased diameter growth,
DIA	= natural log d.i.b. at beginning of growth period in mm
ELEV	= stand elevation above sea level in feet divided by 100
COSINE	= cosine of aspect azimuth in degrees times the slope in percent
SINE	= sine of aspect azimuth in degrees times the slope in percent
SLOPE	= slope in percent
THATFI	= 1 if THPL/ATFI habitat type, 0 otherwise
THPAMY	= 1 if THPL/PAMY habitat type, 0 otherwise
TSPAMY	= 1 if TSHE/PAMY habitat type, 0 otherwise

B(0) =	3.496337	B(3) =	0.007143	[illegible]	[illegible]
B(1) =	1.120681	B(4) =	0.000368 NS	B(7) =	0.538276
B(2) =	-0.018654	[illegible]	0.022533	[illegible]	0.251484 NS[1]

$R^2 = 0.69$

Independent variables tested:

1. Stand location — geographic
2. Habitat type — TSHE/PAMY, THPL/PAMY, ABLA/PAMY, THPL/ATFI
3. Stand elevation above sea level — ft
4. Slope configuration
5. Cosine of the aspect azimuth in degrees times percent slope
6. Sine of the aspect azimuth in degrees times percent slope
7. Natural log diameter inside bark (d.i.b.) at beginning of growth period in mm
8. Breast high tree age at release in years
9. Slope in percent

Dependent variable: DDS

[1]NS = nonsignificant at $P \leq 0.05$, the variable was included because other variables [illegible]

A natural log transformation of the difference between the squared diameters was used to linearize the diameter-growth measurements as follows: $[\ln (D_1^2 - D_2^2)]$ where: D_1 equals the d.i.b. at the beginning of a growth period and D_2 equals the d.i.b. at the end of a growth period. Examinations of plots of the data and other diameter-growth models indicated a [illegible] normal distribution for the squared differences (Wykoff[1]). Using the transformed diameter growth for a 5-year period before treatment as the dependent variable, a nonreleased diameter-growth model was fitted, using all possible regressions for the largest R^2, which [illegible] ($P \leq 0.05$) independent variables. The nonreleased model is a reliable predictor of diameter growth, explaining 69 percent of the variation (table [illegible]

[1]Wykoff, W. R. [illegible] Range Experiment Station, Missoula, MT.

IDENTIFYING SIGNIFICANT ASSOCIATIONS

[illegible]

Results

The diameter-growth response of western redcedar to release from overstory and surrounding competition was related to site, stand, and tree characteristics. Because tree and stand characteristics such as number of trees per acre, tree heights, and stand basal area per acre could not be estimated for past growth periods, these characteristics were used only in the regression models for the 1975-1979 growth period (table 4). Other variables such as stand elevation, slope percent, and slope configuration, were used in the regression models for all periods. The dependent variable in the models was the difference between the observed 5-year diameter growth and the predicted nonreleased 5-year diameter growth.

ZERO TO FIVE YEARS AFTER RELEASE

Five years after release, cosine of the aspect times the slope, natural log d.i.b., b.h. tree age, and the predicted nonreleased diameter growth had significant ($P \leq 0.05$) relationships with the difference between observed diameter growth and predicted nonreleased diameter growth of western redcedar. The best response of western redcedar occurred on the steep north-facing slopes and the poorest response occurred on steep south-facing slopes (fig. 2). Tree d.i.b. had a significant positive relationship with the diameter growth response of western redcedar as indicated by the positive sign of the regression coefficient for the natural log d.i.b. term in the 0- to 5-year regression model (table 4). The positive sign of the natural log d.i.b. term indicated that the larger diameter western redcedar had the better response to release from competition, as compared to the smaller diameter trees. In contrast, the regression coefficient for b.h. tree age in the 0- to 5-year regression model was negative, denoting that as b.h. tree age increased, the diameter growth response of western redcedar to release decreased (table 4). Likewise, the negative coefficient for the predicted diameter growth variable provided evidence that the predicted slower growing trees had better diameter growth response to release than those with the predicted faster growth rates.

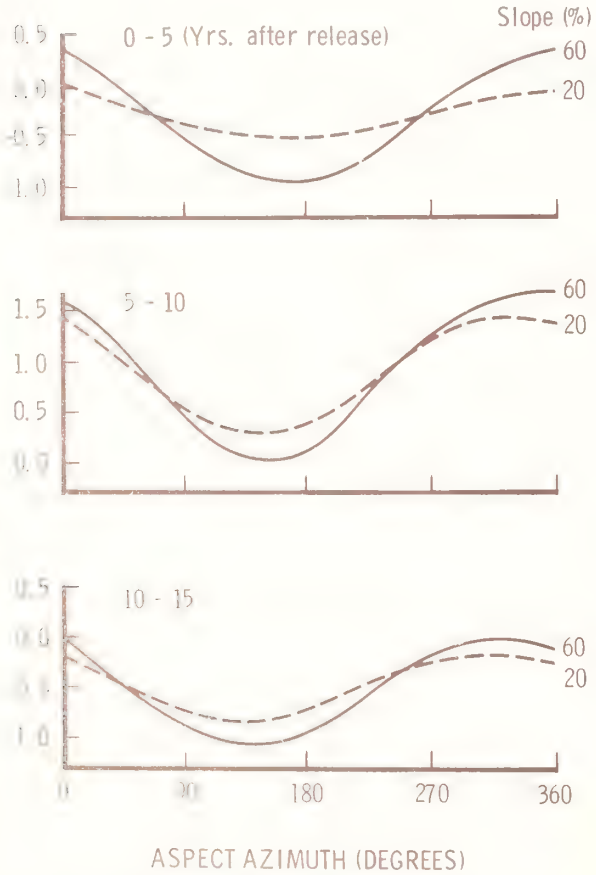


Figure 2.—The 5-year growth response of western redcedar on two slopes for three periods after stand treatment.

FIVE TO TEN YEARS AFTER RELEASE

Slope and aspect, along with b.h. age, had significant relationships with the difference between observed diameter growth and predicted nonreleased diameter growth of western redcedar 5 to 10 years after stand treatment. The diameter growth release response for the 5- to 10-year growth period was better on the steep north-facing slopes than on steep south-facing slopes (fig. 2) and is similar to the results for the 0- to 5-year growth period. In the 5 to 10 years after release, tree age continued to have an inverse relationship with tree response as indicated by the negative regression coefficient in the model for the 5- to 10-year period (table 4).

TEN TO FIFTEEN YEARS AFTER RELEASE

Predicted nonreleased diameter growth, sine-aspect transformation, cosine-aspect transformation, natural log d.i.b., and b.h. age were all significant ($P \leq 0.05$) variables in the observed minus predicted diameter growth model for the 10- to 15-year period (table 4). Predicted nonreleased diameter growth and tree age with negative regression coefficients remained inversely related to diameter growth release response, while natural log d.i.b. continued to have a positive relationship with the release response of western redcedar. The response to release 10 to 15 years after treatment continued to be the best on north-facing slopes and the poorest on south-facing slopes (fig. 2).

1975-79 PERIOD OF GROWTH

All of the site, stand, and tree variables were used in the regression models for the 1975-79 growth period. The number of years between the time each stand was treated and the 1975-79 growth period ranged from 10 to 45 years, with a mean time of 21 years. Stand crown competition factor, CCF, predicted nonreleased diameter growth, natural log d.i.b., b.h. age, and habitat type were variables significant in the regression model (table 4). The results for this period were similar to the results of the other growth periods, with both b.h. age and predicted diameter growth having an inverse relationship with the difference between actual tree diameter growth and predicted nonreleased tree diameter growth (table 4). Total stand CCF was significant ($P \leq 0.05$) and also had a negative regression coefficient

Table 4.—The variables associated with the difference between [illegible]

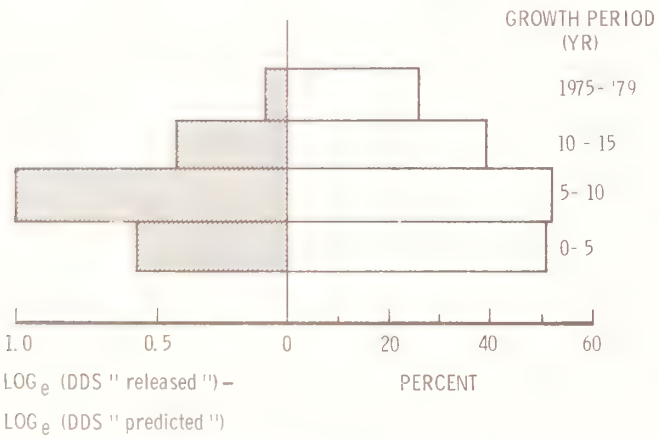
Variable	Significance: Time period since release (years) 0-5	5-10	10-15	1975-79	Regression coefficients: Time period since release (years) [illegible]	5-10	10-15	[illegible]
Location	NS	NS	NS	[illegible]				
Elevation/100	[illegible]	[illegible]	[illegible]	NS				
Slope angle	NS	[illegible]	NS	NS				
Slope config	NS	NS	NS	NS				
Time since release	[illegible]	NS	NS	NS				
d.i.b.	NS	NS	NS	NS				
(d.i.b.)^2	NS	NS	[illegible]	NS				
% sunlight	[illegible]	[illegible]	NT	NS				
Tree height	NT	[illegible]	[illegible]	NS				
Tree crown ratio	[illegible]	[illegible]	[illegible]	NS				
Tree crown class	NT	NT	[illegible]	NS				
Tree damage	[illegible]	[illegible]	[illegible]	NS				
Shrub height	[illegible]	[illegible]	[illegible]	NS				
% shrub cover	[illegible]	[illegible]	[illegible]	[illegible]				
BAP	[illegible]	NT	NT	NS				
BAL	[illegible]	NT	NT	NS				
Point BA	NT	[illegible]	NT	[illegible]				
Point TPA	[illegible]	[illegible]	[illegible]	NS				
Point CCF	[illegible]	NT	NT	[illegible]				
Cluster BA	[illegible]	[illegible]	[illegible]	NS				
Cluster TPA	[illegible]	NT	[illegible]	[illegible]				
Cluster CCF	NT	NT	NT	NS				
Stand BA	[illegible]	NT	NT	NS				
Stand TPA	NT	[illegible]	[illegible]	NS				
Stand CCF	NT	[illegible]	NT	0.0001				0.00[illegible]
Pred. growth	0.0001	NS	0.0046	0001	- 1.087		[illegible]	[illegible]
Cos (Asp)*Slope	.0007	0.0038	0012	NS	012	0.013	013	
Sin (Asp)*Slope	NS	.0112	.0453	[illegible]		010	009	
ln d.i.b.	.0001	[illegible]	.0008	0001	1.538	[illegible]	[illegible]	
b.h. age	0001	.0001	0001	0005	- .014	- 010	010	[illegible]
Habitat type	[illegible]	NS	NS	0108				
THPL/PAMY								
ABLA/PAMY								
TSHE/PAMY								
THPL/ATFI								
Intercept					2.621	[illegible]	[illegible]	[illegible]
R^2					[illegible]	[illegible]	[illegible]	[illegible]

[1]NS = nonsignificant ($P \leq 0.05$)
NT = not tested
[2]Different letters indicate significant differences ($P \leq 0.05$)

indicating that stands with high CCF's had poor diameter growth response. Habitat type was also associated with the response of western redcedar to release. Trees growing on the THPL/PAMY habitat type had the best response, which was significantly different from [illegible] (table 4).

ALL GROWTH PERIODS

The magnitude of the growth response to release differed among the four growth periods. The best diameter growth occurred 5 to 10 years after a release treatment and the poorest growth for the same trees occurred between 1975 and 1979, 21 years after release (fig. 3). Likewise the proportions of trees growing faster than a predicted nonreleased tree differed among the four growth periods. The proportions for the 0-5, 5-10, 10-15, and 1975-79 periods were 51, 52, 39, and 26 percent, respectively (fig. 3).



Diameter-growth response to release appeared to be best on north-facing slopes. Certain characteristics of growing sites on northerly exposures perhaps ameliorate changes in microclimate caused by a release cutting, thus shade-adapted leaves respond favorably to release as shown by increasing tree diameter growth. On north-facing slopes the light sensitive stomata of shade-grown leaves after a release cutting would be open less than the stomata of shade-grown leaves after a release cutting on other exposures. In addition, better leaf turgidity could be maintained, thus reducing the amount of photochemical damage to the shade leaves while new sun-adapted leaves could form. If not damaged excessively when exposed to the sun, shade leaves are capable of increasing in thickness and in weight-to-length ratios. This makes them more sun tolerant (Tucker and Emmingham 1977) and enables the tree to survive changes in microclimate. Other shade-tolerant species also respond to release best on cool, moist sites. These include grand fir (*Abies grandis* [Dougl.] Lindl.) (Ferguson and Adams 1979), amabalis fir (*Abies amabilis* [Dougl.] Forbes) (Herring and Etheridge 1976), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) (Herring 1977), and nutall oak (*Quercus nuttallii* Palmer) Johnson 1975).

Young western redcedar trees appear to respond to release from surrounding and overhead competition better than older trees. Several factors could be involved in changing this relationship, including natural senescence, crown depletion resulting from suppression, and damage due to many kinds of agents. When shade-tolerant trees are grown for long periods in suppressed conditions, their crowns develop to be shorter and thinner than their open-grown counterparts. Because trees with long, dense crowns are the most vigorous they are more likely to respond to release (Graham 1980b; Seidel 1977). Understory western redcedar are often subjected to heavy snow loads that damage the crowns and boles, thus decreasing their ability to respond to release. The capacity of a tree to respond to release generally declines with age (Baker 1950; Ferguson and Adams 1979), but age does not appear to affect the release of some species such as subalpine fir and balsam fir (*Abies balsamea* [L.] Mill.) (Herring 1977).

The larger diameter western redcedar trees in a stand had the better diameter growth responses to release. The larger diameter trees in a stand are usually the taller trees with larger crowns, have more crown that is sun adapted, and have more extensive root systems. Therefore, when a release cut occurs in a stand those trees with larger diameters can respond to the more favorable growing conditions more quickly than smaller trees. The faster growing western redcedar in a stand may have adequate growing space before a release treatment, so any additional space from release cutting would not be utilized. Therefore, prereleased diameter growth rates do not always indicate, as well as d.b.h. does, the growth performance after release. This has also been demonstrated by Baker (1950), Cole and Stage (1972), and Stage (1973).

The diameter-growth response of western redcedar to release was significantly ($P \leq 0.05$) related to habitat types. Western redcedar on the THPL/PAMY habitat type had the best release response. This is the warmest and driest habitat type where western redcedar grows (Daubenmire and Daubenmire 1968). Western redcedar is the climax species on this habitat type and can dominate in eventual size and number over the other species. On the TSHE/PAMY habitat type, western redcedar cannot compete with the other species as readily when released. Any disturbance in stands growing on the TSHE/PAMY habitat type usually results in a tremendous western hemlock regeneration that can compete with the released western redcedar trees. The occurrence of western redcedar on the ABLA/PAMY habitat type is very limited, making release operations marginal. It appears that on this habitat type, western redcedar is limited by cold temperatures. Any release cutting will increase the probability of frost damage to the released trees, making the release treatments less effective. Likewise release treatments on the THPL/ATFI habitat type could be less successful because of cold temperatures and high ground-water tables. Habitat types have also been found related to

the growth of other species [illegible] well as to release response of other species (Ferguson and Adams [illegible]).

Stand density after release was related to the amount of diameter growth western redcedar achieves. Western redcedar stands with high CCF's after release had growth rates less than western redcedar stands with low CCF's. Increases in stand density after release can be partially attributed to additional tree growth in response to the treatment and to new regeneration.

The stresses in western redcedar as it adjusts to a new microclimate after a release cutting could make it more susceptible to attack by *Armillaria mellea* (Vahl. ex Fr.). *Armillaria mellea* is capable of spreading by both root-to-root contact and by rhizomorphs infecting other stump and tree root systems (Boyce 1961; Morrison and Johnson 1978). Frequency of such contact is increased in response to release; i.e., western redcedar's extensive grafted root system expands along with the expansion of ingrowth root systems. This helps facilitate the spread of *A. mellea* throughout the released stand. The mechanical operations of a release treatment can increase the infection rate of *Fomes annosus* (Fr.) Karst. and *Heterobasidion annosum* (Fr.) Bref. in stands of western hemlock (Wallis and Morrison 1975; Chavez and others 1980), but there is no evidence that mechanical damage increases the infection rate of *A. mellea* in released stands. Increasing tree spacing by release cuttings does not prevent the attack of western recedar by *A. mellea*, but it can actually increase disease infection rates.

SOIL CHARACTERISTICS ASSOCIATED WITH THE RELEASE RESPONSE OF WESTERN REDCEDAR

Literature Review

[illegible] significant associatio[illegible] White and Leal (1964, 1965) could [illegible] growth to amounts of total soil po[illegible] Lloyd 1950; Alban 1974). Often the [illegible] predictions more reliable (Steinbrenner 19[illegible] ing upon location and species, tree growth has [illegible]

Methods

DATA COLLECTION

An integrated soil [illegible] Laboratory. These chemical analyses quan[illegible] of western redcedar (table 5).

Table 5.—Chemical characteristics of the soil from 15 stands of released w[illegible]

Characteristic	Mean	Standard deviation	Maximum	Minimum
pH	5.70	[illegible]	[illegible]	[illegible]
Phosphorus (ppm)	3.00	[illegible]	[illegible]	[illegible]
Potassium (ppm)	2448.00	[illegible]	[illegible]	[illegible]
Organic matter (%)	9.13	2.99	[illegible]	[illegible]
Nitrate (ppm)	1.20	[illegible]	[illegible]	[illegible]
Ammonium (ppm)	4.61	2.12	[illegible]	[illegible]
Electrical cond. (μ mhos)	[illegible]	.06	[illegible]	[illegible]
Boron (ppm)	.09	.06	[illegible]	[illegible]
Sulfate (ppm)	8.50	5.00	[illegible]	[illegible]
Zinc (ppm)	2.86	1.09	[illegible]	[illegible]
Manganese (ppm)	134.30	48.20	[illegible]	[illegible]
Copper (ppm)	1.06	[illegible]	[illegible]	[illegible]
Iron (ppm)	367.60	113.00	[illegible]	[illegible]
Total nitrogen (%)	.25	[illegible]	[illegible]	[illegible]

IDENTIFYING SIGNIFICANT ASSOCIATIONS

Regression analysis was used to identify the soil variables significantly associated with the release of western redcedar. The dependent variable in the regression models was the difference between the DDS for released trees and the predicted nonreleased DDS for the same tree (DDS "released" – DDS "nonreleased"). Fourteen soil variables were tested for association with the dependent variable. The predicted diameter growth of each tree was included in each regression model to eliminate variation not related to the release response of the sample trees. Transformed diameter increments for the periods 0-5, 5-10, and 10-15 years after treatment were used as dependent variables in the regression models.

Results

Amounts of several soil nutrients and soil pH were associated ($P \leq 0.05$) with the growth difference between released diameter growth and predicted nonreleased diameter growth of western redcedar. Amounts of soil nitrogen were significantly related to the difference between released diameter growth and the predicted nonreleased diameter growth of western redcedar as denoted by the significant coefficients for the nitrogen variables (table 6). The positive regression coefficients for the nitrate and ammonium variables in the regression models indicated that trees growing on soils with larger amounts of these forms of soil nitrogens had greater release response than trees growing on soils with lesser amounts of ammonium and nitrate. In contrast, amounts of total soil nitrogen were negatively associated with western redcedar diameter-growth response to release. In other words, trees growing on soils with the larger amounts of total nitrogen had poorer diameter growth release response when compared to trees growing on soils with lesser amounts of total nitrogen.

Amounts of soil sulfate and potassium showed positive relationships with the release of western redcedar from overhead and surrounding competition. Both sulfate and potassium had positive regression coefficients in the 0-5- and 10-15-year models (table 6). The regression coefficients indicated that western redcedar growing on soils with the larger amounts of sulfate and potassium had greater diameter growth response to release than western redcedar growing on soils having lesser amounts of sulfate and potassium.

Amounts of soil iron and copper, along with soil pH, had negative relationships with the diameter increment of released western redcedar. The regression coefficients for soil iron, and copper were significant only for 0-5- and 5-10-year periods, with the regression coefficient for soil pH being significant for all growth periods (table 6). These regression coefficients were evidence that the response of western redcedar to release was greater on soils with the lesser amounts of copper, iron, and lower pH values, compared to tree diameter growth on soils with the larger amounts of copper, iron, and higher pH values.

Significant interactions between soil characteristics were detected using two variable regression models. For the 0-5-year time period since release the significant interactions identified were total nitrogen-iron and pH-potassium (table 7). During the 5-10-year time period, the significant interactions detected were total nitrogen copper, total nitrogen-iron, pH-iron, total nitrogen-potassium, pH-sulfate, and total nitrogen-nitrate. Only two significant interactions, total nitrogen-potassium and pH-ammonium, were detected for the 10-15-year period. The significant interactions were evidence that for a given amount of soil constituent the response of western redcedar to release was not proportional to changes of the other constituent in the interaction.

Discussion

Several soil characteristics were significantly ($P \leq 0.05$) associated with the growth difference between the diameter of released western redcedar and the predicted diameter growth of nonreleased western redcedar. Soil variables, including total nitrogen, ammonium, nitrate, sulfate, copper, potassium, iron, and pH had significant regression coefficients in the release response models.

Soil pH directly influences the uptake of soil nutrients by plants. Soil copper, boron, zinc, manganese, potassium, and iron are not readily absorbed by plants at higher soil pH's (Alban 1958). The influence that soil pH has on the availability of soil nutrients for plant growth could explain why western redcedar growing on high pH soils had the poorer response to release. Soil pH could be limiting the uptake of soil nutrients, thereby influencing the diameter increment of released trees. Data for this study did show interactions of pH and potassium having negative relationships with the response of western redcedar to release.

Nitrogen nutrition of forest trees is usually more complex than is the nutrition of other major elements. Nitrogen is most readily available for tree growth in the nitrate and ammonium forms that often can be less than 10 percent of the total nitrogen in a forest soil (Jorgensen 1967). Much of the total nitrogen is immobile or nearly so in organic matter and long periods of time are involved in its breakdown (Shoulders and McKee 1973). Switzer and others (1968) showed that soils of a southern pine ecosystem contained 1,700 lb (1 905 kg/ha) of total nitrogen per acre but only 34 lb (38 kg/ha) per acre were available for tree growth. Therefore it would be possible for western redcedar to have a greater response to release on soils with the greater amounts of available nitrogen, but also a poor response to release on soils with the large amounts of total nitrogen because it is possible that only a small amount of the total soil nitrogen was available for tree growth.

Relationships of tree growth to soil nutrients can easily be confounded by other tree and site variables. Elevation and aspect can influence the availability of soil nutrients (Leaf 1956), as can the tree genotype (Steinback 1971). Likewise, tree rooting habit and the ability of tree roots to penetrate forest soils can affect

Table 6.—Soil characteristics associated with the difference bet

Variables	Significance Time period since release (years) 0-5	5-10	10-15	Regression coefficients Time period since release (years) 0-5	5-10	10-15
Organic matter (%)	[illegible]	[illegible]	[illegible]			
Phosphorus (ppm)	[illegible]	NS	[illegible]			
Electrical cond. (μmhos)	NS	NS	[illegible]			
Boron (ppm)	NS	NS	NS			
Zinc (ppm)	[illegible]	[illegible]	NS			
Manganese (ppm)	NS	NS	NS			
Nitrogen (%)	0.0031	0.0001	0.0001	[illegible]	[illegible]	[illegible]
Ammonium (ppm)	NS	NS	[illegible]			
Nitrate (ppm)	NS	0001	NS	[illegible]	[illegible]	
Sulfate (ppm)	.0001	0001	NS	0969	[illegible]	
Copper (ppm)	.0001	0001	NS	[illegible]	[illegible]	
Potassium/100 (ppm)	.0001	0001	0001	[illegible]	[illegible]	
Iron (ppm)	.0263	.0001	NS	0010	0045	
pH	0001	[illegible]	0001	[illegible]	[illegible]	[illegible]
Predicted growth	.0004	[illegible]	0001	[illegible]	2742	[illegible]
Intercept				7.1217	[illegible]	[illegible]
R^2				34	[illegible]	[illegible]

[1]NS = nonsignificant ($P \leq 0.05$)
Coefficients not estimated for nonsignificant variables

Table 7.—Selected models to test interactions betwee

Model Form: ln (DDS "released") – ln (DDS "nonrel
+ variable (1)*variable (2)

Variable interaction	Significant regression coefficients Time period since release (years) 0-5	5-10	10-15
Total N*K	NS[1]	0.2780	[illegible]
Total N*Sulfate	[illegible]	NS	NS
Total N*Cu	NS	[illegible]	[illegible]
Total N*Fe	0.0220	[illegible]	[illegible]
Total N*pH	NS	NS	[illegible]
Total N*Ammonium	[illegible]	[illegible]	[illegible]
Total N*Nitrate	NS	[illegible]	[illegible]
pH*Sulfate	NS	[illegible]	[illegible]
pH*Cu	NS	NS	[illegible]
pH*Fe	[illegible]	[illegible]	[illegible]
pH*K	3591	[illegible]	[illegible]
pH*Nitrate	NS	[illegible]	[illegible]
pH*Ammonium	NS	NS	[illegible]

[1]NS = nonsignificant ($P \leq 0.05$)
Coefficients not estimated for nonsignificant variables

nutrient [illegible] as cleaning, weeding, and thinning, can alter [illegible] growth [illegible] 1964). Also, methods used to assess fertility of [illegible] cultural soils when used for forest soils may result in erroneous data (Waring and Youngberg 1972). To better assess soil fertility of forest soils, Lea [illegible] Madgwick (1960) suggested modifying agricultural soil tests by including soil volume to better express soil fertility.

TREE FOLIAGE CHARACTERISTICS ASSOCIATED WITH THE RELEASE OF WESTERN REDCEDAR

Literature Review

Foliar nutrient concentrations can be mathematically related to various forms of tree growth. Using multiple regression techniques, Leyton and Armson (1955) determined the critical threshold amounts of foliar nitrogen and potassium for height growth of Scots pine (*Pinus sylvestris* L.). The same methods were used to estimate Japanese larch (*Larix leptolepsis* Murr.) height growth as a function of foliar nutrient concentrations (Leyton 1956). Foliar nutrient quantities can be used to predict basal area, height, and volume growth of red pine (*Pinus resinosa* Ait.) (Hoyle and Mader 1964). Likewise, amounts of nutrients in leaf parts are related to the height and volume growth of sycamore (*Platanus occidentalis* L.) (Haines and others 1979). Using entire tree populations, Stone and others (1958) used foliar nutrient concentrations to predict stand volume. Foliar concentrations of different nutrients can be used to predict site index as demonstrated by Gagnon (1964) and Radwan and DeBell (1980).

Mathematical models predicting tree growth using foliar nutrients can help identify amounts of foliar nutrients that limit tree growth. The relationships of tree growth to foliar nutrient concentrations have been divided into a region of deficiency, a region of critical amounts, and a region of luxury consumption (Barrows 1959; Richards and Bavege 1972; Everard 1973). Leyton (1958), when investigating critical and nutrient requirements for tree growth, found it easier to detect critical nutrient amounts than to find optimum amounts or to predict fertilizer response.

Critical and deficient amounts of foliar nutrients for fruit production have been thoroughly investigated (Sprague 1964) and are continually being refined for different crops and soils (Jones and others 1968; Embleton and Jones 1966; Embleton and others 1971).

Foliage nutrient concentrations for many eastern conifer (Lowry and Avard 1968, 1969; White 1954), and southern conifer (Wells and Metz 1963) populations have been reported. Foliar nutrient concentrations for northwest conifers have been reported by Tarrant and others (1951), Daubenmire (1953), and Beaton and others (1965).

In addition to sampling the natural variation of foliar nutrients of different species, more specific studies were conducted on foliar nutrient deficiencies in conifers. Van den Burg (1979) reported foliar deficiency levels for nitrogen, phosphorus, potassium, magnesium, and manganese in three spruce species. Likewise, Gessel and others (1951) reported preliminary results that identified foliar nutrient deficiencies for western redcedar, and later Walker and others (1955) finalized the mineral requirements for western redcedar. Powers (1976) summarized the deficient and critical foliar nutrient concentrations for conifers, hardwoods, and field crops.

Besides establishing deficiency levels of nutrients for tree growth, many studies have also reported the foliar symptoms of nutrient deficiencies. Foliar nutrient deficiencies of hardwoods have been described by Ashby (1959), Ashby and Mika (1959), Hacskaylo and Struthers (1959), Ike (1968), Phares and Finn (1972), Smith (1976), Perala and Sucoff (1965), and Mader and others (1969). Foliar symptoms of mineral deficiencies of conifers have been described by Walker and others (1955), White and Wright (1966), and Behan (1968).

Methods

DATA COLLECTION

A sample of the most recent foliage was collected at a height of 12 feet (3.7 m) and from the north side of each western redcedar tree on the variable radius plots. As the foliage was collected, its color was identified using the Munsell color notation system (Munsell Color Company 1952; Hamilton 1960). The foliage was kept cold until it was chemically analyzed by the University of Idaho College of Agriculture Plant and Soil Analytical Laboratory. These chemical tests resulted in amounts of 12 foliar nutrients for 601 western redcedar trees in this study (table 8).

IDENTIFYING SIGNIFICANT ASSOCIATIONS

Regression analysis was used to identify the foliar variables significantly associated with the release of western redcedar. The dependent variable in the regression models was the difference between the DDS for released trees and the predicted nonreleased DDS for the same tree (DDS "released" − DDS "nonreleased"). Twelve foliar variables were tested for association with the dependent variable. The predicted diameter growth of each tree was included in each regression model to eliminate variation not related to the release response of the sampled trees. The transformed diameter increment for the 10 years after treatment was used as the dependent variable in the regression models.

Foliar nutrient content was separated by foliar color using discriminant analysis in which 11 Munsell foliar colors and 12 foliar nutrients were used.

Results

The diameter-growth responses of 601 western redcedars to release from overstory and surrounding competition were related to foliar characteristics. Amounts of phosphorous and manganese in foliage of western redcedar had positive, significant relationships with the differences between released diameter growths and predicted nonreleased diameter growths. These relationships were indicated by the positive significant coefficients in the regression models for the phosphorus and manganese variables (table 9). These coefficients were evidence that western redcedar having foliage with the greater amounts of manganese and phosphorus had greater diameter growth response to release than western redcedar having foliage with smaller amounts of manganese and phosphorus.

Foliage concentrations of iron, sodium, potassium, and sulfur had negative significant relationships with the differences in diameter growths of released and predicted nonreleased western redcedars. The negative regression coefficients for foliar iron, sodium, potassium, and sulfur indicated that the diameter increment of released trees with the higher concentrations of

Table 8.—Amounts of foliar nutrients for 601 released western re[illegible]

Nutrient	Mean	Standard deviation	Maximum	Minimum
Zinc (ppm)	16.02	3.01	23.80	
Manganese (ppm)	130.54	34.90	225.00	
Copper (ppm)	5.04	1.16	7.50	
Iron (ppm)	159.14	75.75		
Sodium (ppm)	234.36	89.79		
Potassium (ppm)	5,938.25	[illegible]		4,100.00
Calcium (ppm)	12,678.57	[illegible]		[illegible]
Magnesium (ppm)	1,003.57	173.83		600.00
Sulfur (ppm)	380.68	41.77	468.00	[illegible]
Boron (ppm)	13.97	3.54	22.65	[illegible]
Nitrogen (%)	[illegible]	.12	1.15	.63
Phosphorus (%)	[illegible]	[illegible]		[illegible]

Table 9.—Foliar nutrients associated with the d[illegible]

Nutrient	Coefficient	Significance
Zinc (ppm)		NS
Manganese (ppm)	0.0034	[illegible]
Copper (ppm)		[illegible]
Iron (ppm)	.0033	.0001
Sodium (ppm)	.0042	.0001
Potassium (ppm)/100	.0240	.0001
Calcium (ppm)		NS
Magnesium (ppm)		NS
Sulfur (ppm)	.0121	.0001
Boron (ppm)		NS
Nitrogen (%)		NS
Phosphorus (%)	55.9794	.0001
Predicted growth	.1999	[illegible]
Intercept	−2.0210	[illegible]
R^2	.371	

[1]NS = nonsignificant ($P \leq 0.05$)
No coefficients given for nonsignificant variables

these [illegible] ment of released [illegible]

Using two variable regression models, selected interactions between foliar nutrients were tested. Total nitrogen and phosphorus appeared to have no significant interactions with other foliar nutrients when their association with the release response of western redcedar was tested, as shown in the following tabulation:

Variable interaction	Significant coefficient
[illegible]	[illegible]
[illegible]	[illegible]
N* P	NS
N* Fe	NS
[illegible]	[illegible]
N* S	NS
N* Mg	NS
N* Mn	[illegible]
N* K	NS

NS = non-significant ($P \leq 0.05$)
Model Form [illegible] released") = Predicted growth + variable [illegible] variable (2) + variable (1)*variable [illegible]

[illegible] with green-yellow, greenish green yellow and yellowish [illegible] had [illegible]

Table 10.—Least squares diameter growth response means for different foliar colors

Color[1] Hue	Value	Chroma	Color description	Growth response[2] Least squares mean
5.0 GY	7	[illegible]	Green-yellow	−0.156 a[3]
2.5 GY	[illegible]	[illegible]	Yellowish green-yellow	−.284 a b
5.0 GY	7	1[illegible]	Green-yellow	−.354 a b
5.0 GY	6	[illegible]	Green-yellow	−.362 a b
5.0 GY	[illegible]	[illegible]	Green-yellow	−.419 a b c
5.0 GY	4	6	Green-yellow	−.497 a b c
2.5 GY	6	8	Yellowish green-yellow	−.566 b c
5.0 GY	5	8	Green-yellow	−.623 b c
7.5 GY	6	10	Greenish green-yellow	−.649 b c
2.5 GY	7	8	Yellowish green-yellow	−.660 b c
7.5 GY	5	6	Greenish green-yellow	−.874 c

[1]Munsell color notation (Munsell Color Company 1952).
[2]Adjusted for time since treatment.
[3]Different letters indicate significant differences ($P \leq 0.05$).

Table 11.—Mean foliar nutrient content associated with foliar colors of western redcedar

Color H	V	C	Element N	P	B	Fe	K	Ca	Mg	S	Cu	Zn	Mn	Na
			Percent		*Parts/million*									
2.5GY	[illegible]	[illegible]	0.79	0.11	11.8	170.0	5,033	17,077	922	362	14.9	20.2	146	195
2.5GY	7	8	.91	.12	14.1	147.9	5,979	14,375	1,055	386	8.9	18.3	127	202
2.5GY	6	8	.91	.12	14.1	150.3	5,642	14,210	1,055	377	8.2	17.2	119	230
5.0GY	6	6	.85	.12	13.0	151.5	5,606	14,930	1,016	371	6.9	17.1	129	228
5.0GY	4	6	.95	.13	15.0	172.4	6,446	13,405	1,037	393	5.0	18.1	131	203
5.0GY	7	[illegible]	.93	.13	13.7	129.6	6,227	13,032	999	390	4.8	16.2	127	192
5.0GY	6	8	.90	.13	14.2	159.4	6,030	13,158	1,018	376	7.1	16.5	133	238
5.0GY	5	[illegible]	.93	.13	15.1	168.0	6,096	12,170	1,006	391	8.1	16.7	134	255
5.0GY	7	10	.98	.13	16.0	138.6	7,134	11,037	1,088	410	11.2	17.6	135	227
7.5GY	[illegible]	6	.90	.12	14.8	217.7	5,227	15,427	1,043	415	5.0	15.3	139	230
7.5GY	6	10	.94	.12	16.8	154.0	5,923	13,795	1,154	387	14.9	15.2	116	324
Deficiency level			<1.50[2]	40[2]	15.0[2]	10-80[2]	3,910 – 7,820[2]	1,000 – 2,000[2]	608 – 1,890[2]	2,402 – 4,804[2]	<3.0[3]	<5.0[3]	<16[4]	?

[1]Munsell color notation (Munsell Color Company 1952).
[2]Walker and others (1955).
[3]For conifers (Powers 1976).
[4]For citrus crops (Reiseanauer 1976).

Table 12.—Significant differences in mean nutrient content by foliar color

Color[1] Hue	Value	Chroma	No.	1	2	3	4	5	6	7	8	9	10	11
2.5 GY	5	6	1	•	•									
2.5 GY	7	8	2	—	•									
2.5 GY	6	8	3	D	—	•								
5.0 GY	6	6	4	D	—	—	•							
5.0 GY	4	6	5	D	—	D	D	•						
5.0 GY	[illegible]	8	6	D	—	D	D	—	•					
5.0 GY	6	8	7	D	—	D	D	—	D	•				
5.0 GY	5	8	8	D	D	D	D	D	D	D	•			
5.0 GY	[illegible]	10	9	D	—	D	—	—	D	D	D	•		
7.5 GY	[illegible]	6	10	D	D	D	D	D	D	D	D	D	•	
7.5 GY	6	10	11	D	D	D	D	D	D	D	D	D	D	•

[1]Munsell color notation (Munsell Color Company 1952).
[2]D = significant differences at ($P \leq 0.05$) for 12 nutrients: B, Fe, N, P, K, Ca, Mg, S, Cu, Zn, Mn, Na.

follows: boron, 15 ppm; nitrogen, 1.50 percent; phosphorus, 0.40 percent; and sulfur, 2,402 ppm (Walker and others 1955) [illegible] western redcedar, however, concentrations were found to be low: boron, 11.8 ppm; nitrogen, 0.79 percent; phosphorus, 0.11 percent; sulfur, 362 ppm. Also foliar amounts of potassium and magnesium approached the deficiency concentrations reported by Walker and others (1955) for western redcedar.

Discriminant analysis simultaneously detected differences in the mean nutrient content [illegible] different nutrients in the foliage of released western redcedar. Foliage with colors 5.0 GY 5/8, 7.5 GY [illegible] and 7.5 GY 6/10 were individually unique in nutrient content (table 12). Likewise, foliage with color 2.5 GY 5/6 had significantly different nutrient content than all other colored foliage except foliage with color 2.5 GY 7/8.

Discussion

Western redcedar foliar characteristics were related to the differences between released and predicted nonreleased tree diameter growths. Amounts of foliar manganese, iron, sodium, potassium, sulfur, and phosphorus were significantly ($P \leq 0.05$) related to the diameter growth response of western redcedar.

The antagonistic effect of one plant nutrient to another plant nutrient could explain some of the relationships between foliar nutrients and the response of western redcedar to release. Foliar phosphorus had a positive significant relationship with the release response of western redcedar and also appeared to be deficient when compared to the amounts reported by Walker and others (1955). Magnesium can restrict the uptake and accumulation of phosphorus by trees (Gyst and others 1975). In contrast, in the data presented here on the release of western redcedar, an interaction between magnesium and phosphorus could not be detected. Although an interaction could [illegible] larger amounts of foliar magnesium could possibly result in larger amounts of foliar phosphorus, which in turn could result in greater diameter growth response of western redcedar to release.

The negative relationship of foliar potassium to the release response of western redcedar from competition could be caused by the deficient amount of nitrogen found in the western redcedar foliage. Nitrogen [illegible] known to interfere with the uptake and accumulation of potassium in tree foliage (Brendenmuehl 1968; Benzian and Freeman 1967). Therefore, the negative relationship of potassium to release could actually be a nitrogen deficiency expressed by potassium even though an interaction between potassium and nitrogen could not be detected. Perhaps no interaction was detected because potassium is highly mobile within a tree (Bukovac and Wittwer 1957); therefore, adequate amounts for foliage metabolism can be supplied through redistribution within the tree (Switzer and Nelson 1972).

The nitrogen deficiencies that appeared in the [illegible] of released western redcedar [illegible] tive relationships of sodium and sulfer to th[illegible]

[illegible] colors. The relationships of foliar colors and an[illegible] available for tree growth, with the rem[illegible] western redcedar could alter foliage color [illegible] released western redcedar and the predicted diameter [illegible]

CONCLUSIONS

[illegible] increase in response to release from [illegible]

after release when compared to trees growing on soils having smaller amounts of these nutrients.

Tree characteristics were also associated with the release response of western redcedar. The larger the tree diameter at the time of release the greater was its growth after release. Also, the younger the tree at the time of release the better its growth after release.

Foliage color was associated with tree growth and nutrient content of the foliage. Trees with green-yellow foliage had greater growth rates than trees with greenish-yellow foliage. Discriminant analysis simultaneously detected differences in mean nutrient contents for 12 different nutrients in the foliage of released western redcedar.

The results of this study emphasize the importance of site, stand, and tree characteristics in the amount of response western redcedar trees have after they are released from overhead and surrounding competition. The species will respond favorably to release, depending on tree size, tree age, habitat type, slope, aspect, and soil nutrient content.

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Fifteen western redcedar stands were sampled to determine the magnitude and duration of growth response to release treatments. Site factors such as slope and aspect were related to the growth response, as were tree characteristics such as age and diameter at breast height. In addition both foliage characteristics and soil characteristics were related to the growth response.

KEYWORDS: diameter increment, foliar elements, diameter regression model, soil elements

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**Intermountain
Forest and Range
Experiment Station
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Tree Dynamics in Seral and Stable Aspen Stands of Central Utah

Roy O. Harniss and Kimball T. Harper

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RESEARCH SUMMARY

Changes in tree number and basal area were examined in 48 aspen *(Populus tremuloides)* stands after 8 years on the Wasatch Plateau, central Utah. The number of trees declined in the aspen stands where the conifers were not increasing (stable), but basal area did not change during this period. In seral stands both number of aspen trees and basal area decreased while conifers increased in both number and basal area. Some conifer reproduction did appear in the stable stands, but survival rate was low. A difference in structure observed between stands dominated by white fir *(Abies concolor)* and stands dominated by subalpine fir *(Abies lasiocarpa)* was linked to stand age. Rates of increase in conifer basal area were not much different between stands dominated by white fir and those dominated by subalpine fir, but the rate of increase in conifer tree numbers was nearly double in the stands supporting white fir. Rate of aspen tree loss in the stands supporting white fir was nearly three times the rate of loss in stands supporting subalpine fir.

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Tree Dynamics in Seral and Stable Aspen Stands of Central Utah

Ray C. [illegible] and [illegible] T. [illegible]

INTRODUCTION

[illegible]
tree species on the [illegible]
1965). This feature [illegible] en has contrib[illegible]
flicting hypotheses [illegible] ts role in plan[illegible]
Generally, aspen forests are considere[illegible]
over much of their range (Baker 1981, Shirley 1941);
however, aspen forests are also no[illegible]
in Canada (Bird 1930, Moss 19[illegible]
United States (Fetherolf 19[illegible]
Langenheim 1962). M[illegible]
ecosystem are influenced by the successional status of
aspen, as well as the rate of succe[illegible]
the range, wildlife, and watershed attrib[illegible]
stands are greatly diminish[illegible]
established.

Our objectives are to [illegible]
structure and growth rates in both [illegible]
relatively stable aspen stands. This compar[illegible]
made possible by the remeasurement o[illegible]
plots established by K. T. Harper for st[illegible]
succession.

STUDY AREA

The study location is on the Man[illegible]
Forest, mostly within the Great Ba[illegible]
Range in central Utah. Within 4.5[illegible]
terrain rises 3,500 ft (1 067 m) [illegible]
aspen, aspen, spruce-fir, and alpi[illegible]
associations (Keck 1972).

Elevations of the study sites r[illegible]
to 10,000 ft (2 500 to 3 050 m). S[illegible]
60 percent. The general aspe[illegible]
exist with nearly every expo[illegible]
residual clays to sandy clay loams deri[illegible]
limestone and sandstone parent ma[illegible]

[illegible]

[illegible]

[illegible] 969 on the
[illegible]

per acre were summarized by 1-inch (2.54-cm) size classes on each macroplot. The size class designation denotes the smallest diameter included in the size class (for example, the 6-inch [15.24 cm] size class includes all diameters from 6.0 to 6.9 inches [15.24 to 17.53 cm]). Microplot data were summarized by number of trees in less than 1 ft, 1 to 6 ft, and 6 ft tall to 4-inch (<0.3 m, 0.3 to 1.8 m, and 1.8 m tall to 10.16-cm) d.b.h. size classes to evalute tree reproduction for each plot. Differences in tree numbers and basal area between the 1969 and 1977 data were used to evaluate growth rates.

The **t** statistic for paired observations was used to evaluate sample differences for the same macroplots in different years. The general **t** statistic for unpaired means was used to evaluate the differences between seral and stable aspen stands (Ostle and Mensing 1963). Only **t**-values larger than tabular values in the 0.05 probability column were declared statistically significant.

RESULTS AND DISCUSSION

Aspen-White Fir Stands

The stable stands selected in the white fir zone range in elevation from 7,800 to 9,000 ft (2 375 to 2 740 m) with slopes from 4 to 45 percent. Exposure generally ranges northeast to northwest with one plot nearly due south. The seral aspen stands in the white fir zone range in elevation from 7,800 to 8,900 ft (2 375 to 2 710 m). Slopes range from 45 to 50 percent.

Numbers.—The number of trees (d.b.h. >4 inches [10.2 cm]) in stable aspen stands declined 10 percent between 1969 and 1977 (table 1). Most of the losses were in the smaller d.b.h. size classes. The number of aspen trees under 4 inches d.b.h. (10.2 cm) did not change significantly between 1969 and 1977 on the stable plots. There may have been an increase in aspen in the two size classes less than 6 ft (1.8 m) tall, but large variations in the number of trees under 4 inches d.b.h. among the stands masked the effect. Conifer reproduction occurs, but most trees are under 1 ft (0.3m) tall and only one conifer has survived to reach tree size in the stable aspen stands.

The number of aspen trees (d.b.h. >4 inches [10.2 cm]) in the seral aspen stands declined 20 percent while the number of conifer trees increased 17 percent between 1969 and 1977 (table 1). In terms of stand composition (table 2), the relative number of aspen trees declined about 6 percent while white fir increased 6 percent in number of trees over the 8-year period. The rest of the conifers showed little change in relative composition. The number of aspen less than 4 inches d.b.h. in the seral stands was not significantly different from that in the stable stands, except for the class over 6 ft (1.8 m) tall which was lower (table 1). Conifers less than 1 ft (0.3 m) tall were numerous in 1969 in the seral stands, but in 1977 showed a tenfold decrease, probably due to yearly variation in conditions necessary for seedling germination. Conifer numbers in the category with height over 6 ft (1.8 m), but less than 4 inches (10.2 cm) d.b.h. were not particularly abundant and, as in the 4- and 5-inch (10.2- and 12.7-cm) d.b.h. size classes, they may be showing the effects of competition from the mature conifers.

The number of aspen trees (d.b.h. >4 inches [10.2 cm]) in stable stands decreased at a rate of 1.3 percent per year (table 3). In seral stands the rate of loss in aspen trees was 2.5 percent per year or about double that observed in the stable stands. Conifer numbers increased at a rate of 2.1 percent per year in the seral stands.

Basal Area:—The stable aspen stands did not change significantly in aspen basal area between 1969 and 1977 (table 4). In contrast, aspen basal area decreased in the seral aspen stands and conifer basal area increased between 1969 and 1977. The relative stand basal area of aspen declined 10 percent over the 8-year period in the seral stands (table 2). White fir basal area increased 8 percent during that period.

The rate of loss in aspen basal area was 1.3 percent per year in the seral stands (table 3). In contrast, conifer basal area increased at a rate of 5 percent per year, with white fir alone increasing 6.4 percent per year.

The seral aspen stands had a greater total basal area than the stable aspen stands because of the conifers. In the stable stands, the lack of change in basal area with the concomitant decrease in trees seems to indicate a maturing and stabilizing of the aspen forest. The decrease in aspen basal area and increase in conifer basal area in the seral aspen stand is viewed as the normal pattern of succession to conifers.

Table 1.—Average number of tr[illegible]
and aspen-subalpine fir cover[illegible]

Reproduction class	Stable aspen							
	Aspen-white fir							
	[illegible]	1977	1969	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
<1 ft	50	345	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 ft-6 ft	245	495	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6 ft-4 in	485	560	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tree d.b.h.								
4	222	[illegible]			[illegible]	[illegible]		
[illegible]	122	116	[illegible]	[illegible]	[illegible]	[illegible]		
6	80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
8	39	[illegible]			[illegible]	[illegible]		
9	19	[illegible]			[illegible]	[illegible]		
10	[illegible]	12			[illegible]	[illegible]		
11	[illegible]					[illegible]		
12	5				[illegible]	[illegible]		
13	[illegible]				[illegible]	[illegible]		
14	2				[illegible]	[illegible]		
15	[illegible]					[illegible]		
16	[illegible]					[illegible]		
17								
18								
19		1						
20		1						
>21								
Tree total[2]	[illegible]	536			[illegible]	[illegible]		
(Trees/ha)	(1473)	(1324)			[illegible]	[illegible]		

Reproduction class	Aspen-white fir							
	[illegible]pen		Con[illegible]		[illegible]			
	[illegible]	1977	1969	1977	[illegible]	1977	[illegible]	[illegible]
<1 ft	100	315	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 ft-6ft	105	175	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6 ft-4 in	[illegible]	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tree d.b.h.								
4	156	[illegible]	[illegible]	[illegible]				
5	166	134	[illegible]	[illegible]		[illegible]		
6	114	[illegible]	[illegible]	[illegible]		[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
8	49	[illegible]	[illegible]	[illegible]				
9	[illegible]	[illegible]						
10		[illegible]	[illegible]					
[illegible]	1	[illegible]	[illegible]					
[illegible]	[illegible]	[illegible]						
[illegible]								
[illegible]								
[illegible]								
16								
17								
[illegible]								
[illegible]								
[illegible]								
>21								
Tree total[2]	559	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(Trees/ha)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 2.— Percent composition of seral aspen cover types for 1969 and 1977 in two forest types

Species	Aspen-white fir				Aspen-subalpine fir			
	Tree numbers		Basal area		Tree numbers		Basal area	
	1969	1977	1969	1977	1969	1977	1969	1977
Aspen	83	77	70	60	71	67	64	56
White fir	13	19	18	26	T	T	1	1
Subalpine fir	1	1	1	1	26	29	30	37
Blue spruce[2]	3	3	11	13	1	1	2	2
Engelmann spruce[3]					1	1	2	2
Douglas-fir[4]	T	T	T	T	2	2	2	3
Conifer	17	23	30	40	29	33	36	44

[1]T = trace, less than 1 percent
[2]*Picea pungens*
[3]*Picea engelmannii*

Table 3.— Rate per year change in tree numbers (number/yr) and basal area (ft²/yr) for seral and stable aspen

Category and Species	Aspen-white fir				Aspen-subalpine fir			
	Tree numbers		Basal area		Tree numbers		Basal area	
	Per yr	%/yr	Ft²/yr	%/yr	Per yr	%/yr	Ft²/yr	%/yr
Stable plots								
Aspen	-7.5	-1.3	0.4	0.3	-1.6	-0.4	-0.8	0.7
Seral plots								
Aspen	-14.1	-2.5	-1.4	-1.3	-5.6	-1.4	-1.4	-1.2
White fir	2.1	2.3	1.8	6.4				
Subalpine fir					1.1	.7	1.8	3.4
Blue spruce	.3	1.5	.4	2.4				
Englemann spruce					.1	1.4	.2	4.3
Douglas-fir					.0	.0	.2	3.6
Total conifer	2.5	2.1	2.3	5.0	1.3	.8	2.2	3.4

Table 4.—Basal ar[illegible]
and aspen-subalp[illegible]

	Stable aspen		Aspen-w[illegible]				Aspen-subalpine fir					
	Aspen		[illegible]		[illegible]ifer		Stable [illegible]		[illegible]		[illegible]ifer	
d.b.h.	1969	1977	1969	1977	1969	1977	1969	[illegible]	1969	[illegible]	[illegible]	1977
4	21.6	20.4	15.5	12.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	18.1	18.2	24.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	18.8	16.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.0	[illegible]	[illegible]	[illegible]	[illegible]
7	18.6	16.3	22.6	[illegible]	[illegible]	5.9	[illegible]	12.0	[illegible]	[illegible]	[illegible]	4.8
8	14.3	15.8	6.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.1
9	8.9	10.8	4.9	4.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8.5	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	8.5	[illegible]	10.2
[illegible]	[illegible]	6.3	[illegible]	[illegible]	[illegible]	[illegible]	4.9	[illegible]	[illegible]	[illegible]	[illegible]	8.1
12	4.1	8.2	1.6	8	[illegible]	[illegible]	[illegible]	11.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.1	[illegible]	6.0	[illegible]
[illegible]	2.2	3.4	[illegible]	[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]	5.6	[illegible]	[illegible]
[illegible]	1.2	2.5	1.2	[illegible]	1.3	[illegible]	[illegible]	[illegible]	[illegible]	6.5	[illegible]	[illegible]
16	2.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.9	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	2.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	2.3	[illegible]	[illegible]	2.2	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	9.1	12.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	132.3	135.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(m^2/ha)	*(30.4)*	*(31.0)*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Aspen-Subalpine Fir Stands

The stable and seral aspen stands selected in the subalpine fir zone range in elevation from 8,600 to 10,500 ft (2 620 to 3 200 m). Exposures tend to be northeast to northwest at the lower elevations and southeast to southwest at the higher elevations. Slopes range from 2 to 45 percent.

Numbers.—The number of aspen trees (d.b[illegible] inches [10.2 cm]) in the stable stands did not change significantly between 1969 and 1977 (table 1.) Aspen reproduction in the 1- to 6-ft (0.3- to 1.8-m) class increased significantly between 1969 and 1977. Conifer reproduction was present in the stable stands, but showed little tendency to grow taller than 6 ft (1.8 m).

The number of aspen trees (d.b.h. >4 inches [10.2 cm]) in the seral stands decreased about 11 [illegible] cent during the 8-year period while the number of [illegible]fer trees (d.b.h. >4 inches [10.2 cm]) increased about 6 percent (table 1). In terms of stand composition, the relative number of aspen trees decreased 4 [illegible] tween the 2 years and conifer trees increased 4 percent (table 2). The decline in aspen tree numbers generally appeared to be in the 4-, 5-, and 6-inch (10.2-, 1[illegible] and 15.2-cm) d.b.h. size classes. Most of the conifers that established on the plots were subalpine fir. The [illegible] significantly between 1969 and 1977 (table 1). Conifers under 1 ft (0.3 m) tall were numerous in both years, but were most abundant in 1969. The decreasing number of conifer regeneration in successively larger size classes in both 1969 and 1977 seems to be related to high mortality rates in the early years of life.

Aspen tree numbers declined at a rate of 1.4 percent [illegible] the seral aspen stands, but did not change in the stable stands (table 3). Conifer numbers in[illegible]sed at 0.8 percent per year on the seral stands.

Basal area.—There was no significant change in total [illegible] table stands between 1969 and 1977. [illegible] decreased significantly and conifer basal area increased significantly between 1969 and 1977. The decline in aspen basal area in the seral stands appears to be [illegible] b.h. size classes. In terms [illegible] and composition, the relative basal area of aspen [illegible] counting for most of the conifer increase (table 2). Aspen basal area declined between 1969 and 1977 at a [illegible] conifer basal area increased at a rate of 3.4 percent per year (table [illegible]).

Aspen-White Fir Versus Aspen-Subalpine Fir

The seral aspen-white fir stands have more aspen trees (mostly in the 4- to 7-inch [10.2-to 17.8-cm] d.b.h. size classes) than do the seral aspen-subalpine fir stands (table 1); however, the aspen-subalpine fir stands have more aspen trees over 8 inches (20.3 cm). Conifer trees are more abundant in the aspen-subalpine fir stands than in the aspen-white fir stands (table 1). This trend generally holds over all conifer d.b.h. size classes but especially so in the larger d.b.h. size classes.

There was little difference in the total basal area of aspen between the two seral types (table 4). In 1977, about 75 percent of the aspen basal area however was in the smaller (4- to 7-inch [10.2- to 17.8-cm]) d.b.h. size classes in the white fir stands, while in the subalpine fir stands only about 45 percent of the aspen basal area was in these smaller d.b.h. size classes. Conifer basal area was larger in the aspen-subalpine fir stands than in the aspen-white fir stands. In 1977, conifer basal area was about equal in the seral types in the 4- to 7-inch (10.2- to 17.8-cm) d.b.h. classes, but there was more conifer basal area in the subalpine fir type in the larger size classes.

Because the conifers in the aspen-subalpine fir stands were older than conifers in the aspen-white fir stands, some of the structural differences between the types can be explained. The average age of the oldest subalpine fir was about 83 years, the average age of the oldest white fir, 58 years (table 5). The age for the subalpine fir coincides with a period of very heavy grazing on the Wasatch Plateau (Keck 1972). Such heavy grazing ceased shortly thereafter, and may have released the conifers by reducing trampling and utilization.

Differences in ages between the conifers in the subalpine fir and in the white fir stands may also have been influenced by fuel wood and timber harvesting activities. In about 1920, the Forst Service began to control and manage these activities. The difference could also be related to patterns in fire suppression. The average age of the oldest aspen tree was greater in the seral aspen-subalpine fir stands than in the seral aspen-white fir stands (table 5). This difference in age may relate to the burning history of much of this country and to the likelihood that the higher subalpine fir stands did not burn as often as the lower white fir stands.

Management Alternatives

Aspen forests are ideal for wildlife, watershed, range, and recreation, and the deleterious effect that conifer succession over the long term has on these values suggests that management practices (such as burning, spraying, or cutting) that maintain aspen would be beneficial. A discussion of ecological trends for these values in aspen is included in Harniss (1981). The differing successional rates for the white and subalpine fir stands suggested by the basal area and number of trees infer that the associated conifers should be considered in the selection of aspen stands for manipulation. Removal of conifers from the aspen-subalpine fir stands would maintain multiple use values longer because of slower encroachment of fir and spruce.

The consequences of letting succession proceed to conifers would negatively affect range, water, recreation, and wildlife values. Understory production may be reduced more than one-half when conifer basal area increases to 20 ft^2 (1.9m^2) per acre (Harper 1973). Assuming average values for conifer basal area and age (table 5) and that an exponential curve would approximate conifer growth over time (Ward and Bartos 1981), 20 ft^2 (1.9 m^2) of conifer basal area would occur in about 50 years in the white fir stands and about 67 years in the subalpine fir stands. Water yields are expected to decrease 5 percent as conifer succession occurs and replaces the aspen-oak forests of the Unita Mountains (Harper 1981). Because plant diversity and production are much less in conifer than in aspen stands, wildlife habitat is reduced. Many recreational activities are linked to the aspen forest.

Clearcutting of aspen-conifer stands, possible for fuel wood, in small 1- to 4-acre patches would decrease the conifers and rejuvenate the aspen. Setting the aspen back to the suckering stage would be desirable in many mature aspen stands where more wildlife habitat

Table 5.—Average age of oldest tree in the stable and seral aspen types

	Age[1]			
	Aspen-white fir		Aspen-subalpine fir	
Tree	Stable	Seral	Stable	Seral
Aspen	126.0 ± 19.4[1]	121.9 ± 9.0[1]	140.6 ± 37.3[1,2]	162.7 ± 37.3[2]
Conifer		58.6 ± 14.0[1]		83.4 ± 20.0[2]

[1]Age ± standard deviation; numbers that differ in same row are significant at 0.05 level.

is desired. Selective cutting of the conifers [illegible] succession for Christmas trees or poles would [illegible] an aspen stand and the related mu[illegible]

Burning is a management alternative in aspen-conifer because (1) it is a natural process that has occurred many times in the aspen ecosystem [illegible] patterns are beneficial for many multiple-use values, and (3) it is relatively inexpensive.

Spraying might be a valuable tool if use [illegible] quality multiple-use sites in areas that are not v[illegible] and not accessible to or little used by the public. Time of spraying might be used to selectively kill only conifers or aspen or both [illegible] concentration might be adjusted to obtain a certain percent kill or perhaps to initi[illegible] weakening the overstory aspen.

On sites where the conifers timber growth and [illegible] is high and the other resources values are secondary, succession should be accelerated by eliminating [illegible] aspen.

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Changes in tree number and basal area were examined in 48 aspen *(Populus tremuloides)* stands after 8 years on the Wasatch Plateau, central Utah. The number of trees declined in stable aspen stands, but basal area did not change during this period. In the seral stands, number of aspen trees and basal area decreased while conifers increased in number and basal area. Some conifer reproduction did appear in the stable stands, but survival rate was low. A difference in structure between stands dominated by white fir *(Abies concolor)* and stands dominated by subalpine fir *(Abies lasiocarpa)* was linked to stand age. Rates of increase in conifer basal area were not much different between stands dominated by white fir or by subalpine fir, but the rate of increase in conifer tree numbers was nearly double in the white fir stands. Rate of aspen tree loss in the white fir stands was nearly three times greater than the rate of loss in the subalpine fir stands.

KEYWORDS: stable aspen, seral aspen, succession, Utah,tree numbers, tree basal area, stand dynamics

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Histological Differentiation Among Abiotic Causes of Conifer Needle Necrosis

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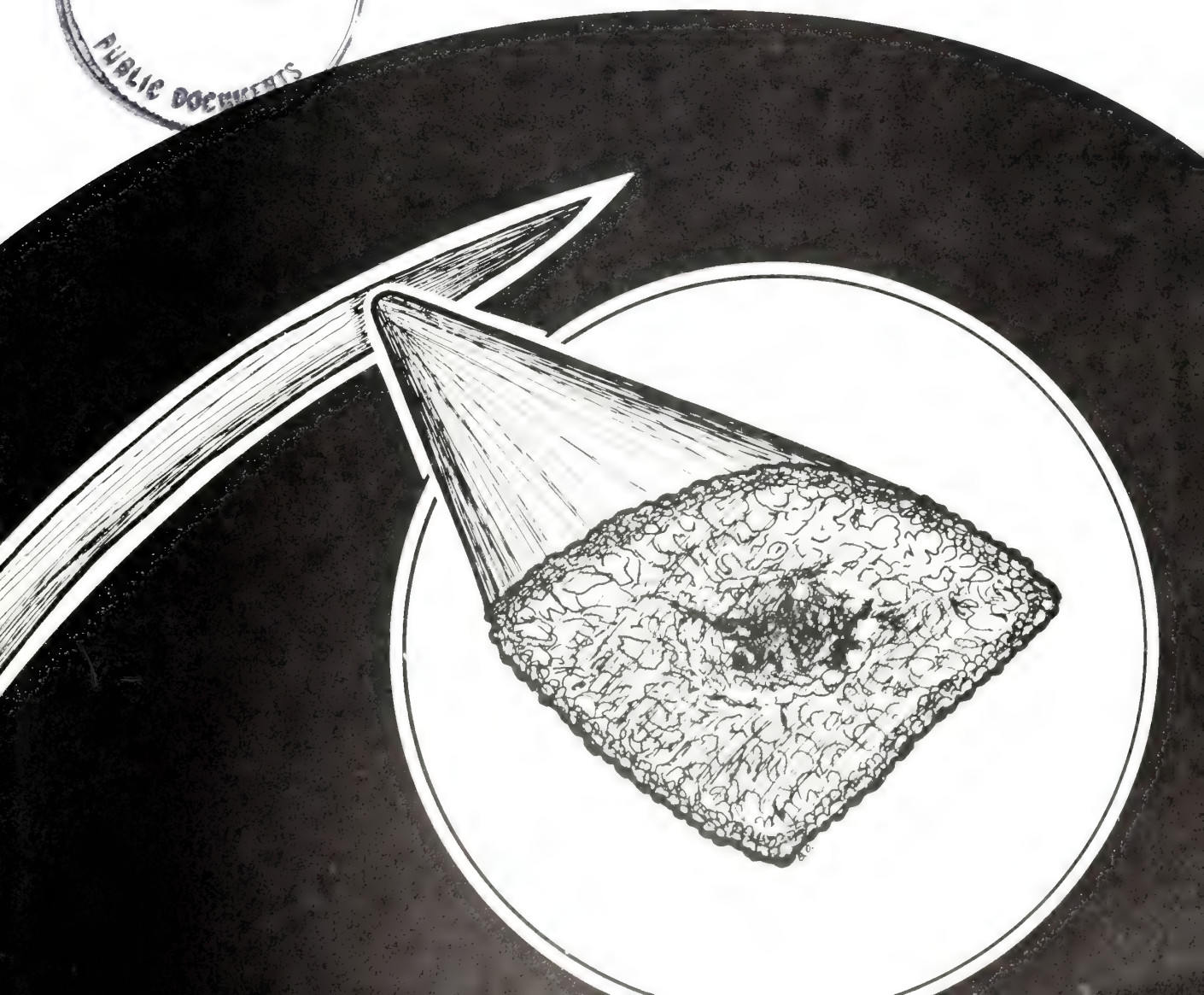

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RESEARCH SUMMARY

Histological analyses of pollutant-caused necrosis of *Pinus ponderosa* and *Pseudotsuga menziesii* current-year foliage laboratory-fumigated with hydrogen fluoride, sulfur dioxide, and ethyl mercaptan, showed that necrosis caused by phytotoxic gases can be differentiated from that induced by winter drying, drought, and salt. Hypertrophy and hyperplasia of vascular parenchyma, endodermis collapse, and intense vascular staining were characteristic of injury caused by the pollutants in both species, but were not found in needles injured by the other causes.

Similar analyses were done on necrotic 2- to 3-year-old conifer foliage collected in the field near industrial sources of fluoride, sulfur dioxide, mercaptans, and hydrogen sulfide and from specimens collected from sites known to have been injured by winter drying. Species included *Pinus contorta*, *Pinus ponderosa*, *Pseudotsuga menziesii*, *Pinus sylvestris*, and *Pinus flexilis*. As in the laboratory fumigations, winter drying injury was readily distinguished from that caused by phytotoxic gases. The internal symptoms caused by industrial fumigations were similar to those induced by gases under controlled conditions and symptoms of winter drying from field-collected specimens were similar to those simulated in the laboratory. These results differ substantially from conclusions reached in a similar study in 1973. The present study shows that histological analysis should be useful in diagnosing air pollution-induced injury and damage in coniferous forests.

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INTRODUCTION

Conifer needle necrosis and chlorosis can be induced by several agents including salt (Spotts and others 1972); winter drought (Carlson and Meyer 1973); air pollutants including fluoride, sulfur oxides, reduced sulfurs (Treshow and Pack 1970; Carlson and others 1974; Weinstein 1977); and presumably other causes. Field studies of air pollution-related injury and damage to conifers near emitting sources involve a great deal of subjectivity in the identification of cause. Even though foliar chemical analyses may indicate accumulation of a pollutant in a forest, relationships of needle abnormalities to the contaminant may remain obscure (Treshow 1969). Solberg and Adams (1956), Carlson and Dewey (1971), and Gordon (1972) suggested that light microscopy of sections of affected needles may be diagnostic. Sections were made in a transition zone defined as a ca. 0.08 in (2 mm) needle segment that includes healthy, chlorotic, and necrotic tissue. However, Stewart and others (1973) claimed that fluoride, salt, and winter damage caused virtually identical histological changes within symptomatic needles.

The purpose of this research was to determine whether abiotic causes of necrosis induce differential symptomatology in conifer needle tissue; the work involved laboratory and field studies.

METHODS

Laboratory Study

Two-year-old *Pseudotsuga menziesii* and *Pinus ponderosa* seedlings were obtained in late winter from the Forest Service nursery at Coeur d'Alene, Idaho, transplanted while dormant to 8-inch clay pots, and placed in a greenhouse. The potting medium was 70 percent nursery soil and 30 percent composted sawdust. No fertilizer was added, and pots were watered evenly every 3 or 4 days. Greenhouse temperature and humidity were recorded on a hygrothermograph throughout the experiment. The first 2 weeks following transplanting, greenhouse temperature was kept at ca. 50° F (10° C) and photoperiod at 16 hours with 550 fc (foot-candles) to minimize transplant shock. Temperature then was increased to 70° F (21° C) during the day and was allowed to drop to 50° F (10° C) at night. Bud break occurred ca. 3 weeks after transplanting. Needle development appeared normal and there was no visible evidence of transplant shock. Four months after transplanting, new foliage was fully elongated and the seedlings were physiologically active. By this time, temperature fluctuated diurnally between 50° to 91° F (10° to 33° C) and light intensity varied between 500 and 6,000 fc, depending on cloud cover. Relative humidity varied from 45 to 85 percent, averaging ca. 65 percent. Seedlings did not exhibit adverse effects due to greenhouse environmental conditions.

Several phytotoxic gases commonly emitted from industrial sources located near coniferous forests and other abiotic stresses often suggested as alternative causes of foliar injury were selected as treatments. Seedlings of each species were randomly segregated into eight groups of ten each. Each group of ten seedlings was subjected to one of the following randomly assigned treatments: control, excessive salt, drought, simulated winter drying, sulfur dioxide (SO_2), hydrogen sulfide (H_2S), ethyl mercaptan (C_2H_6S), and hydrogen fluoride (HF). All treatments except controls were administered specifically to develop foliar injury; when injury was noted seedlings were removed to the normal greenhouse environment. Treatments are detailed below.

CONTROL

Seedlings were placed in a stainless steel chamber of 18 ft^3 (.51 m^3) internal volume with plexiglass roof and windows. The chamber was refrigerated to maintain relatively constant temperatures and light was provided with a bank of fluorescent and incandescent lights emitting about 1,500 fc at tree level. Temperature was maintained at 68° to 77° F (20° to 25° C) and relative humidity at 50 to 60 percent.

Charcoal-filtered air was supplied to the chamber through a Worthington air compressor at ca. 1.77 ft^3/min (50 l/min) for 72 hours. Seedlings were then removed to the normal greenhouse environment.

SALT

Seedlings were placed in a separate watering tray and watered every 2 to 3 days for 7 weeks with a 1.2 percent (12,000 ppm) solution of NaCl according to Spotts and others (1972). Salt-free water then was applied for the duration of the experiment.

DROUGHT

Water was withheld from the seedlings for 22 days, at which time needles showed obvious visible symptoms of moisture stress. Normal watering then was resumed.

SIMULATED WINTER DRYING

A sheet of 1/2-inch (1.26-cm) thick plywood was fitted to the top of a chest-type freezer. Holes were cut large enough in the wood to allow insertion of the lower portion of the pots; the pot lip prevented the container from falling through the hole. The freezer lid was left open, the board was placed over the opening, and the pots with seedlings were inserted (fig. 1). Freezer temperature was maintained at 0° F (–18° C), effectively freezing the soil and seedling roots while the tops remained at greenhouse temperature. Soil and freezer temperatures were monitored daily. After 3 days of freezing, a small oscillating fan was placed about 8.2 ft (2.5 m) from the freezer; the fan cast a light breeze over the seedlings. Except for the relatively high greenhouse temperatures, this treatment simulated winter drought conditions. Foliar chlorosis appeared 2 days later and the treatment was discontinued. The pots then were placed in the normal greenhouse environment.

Figure 1.—Apparatus used to induce winter drying. The pot bases were subjected to freezing temperatures, freezing the soil and root systems, while the stems and needles were maintained at greenhouse temperature. A light breeze generated by a small fan directed over the seedlings completed the winter drying simulation.

SULFUR DIOXIDE

Seedlings were placed in the chamber described for the control treatment. Sulfur dioxide was obtained from Matheson Gas Co. in a pressurized tank at 1 percent SO_2 in air. Tank SO_2 was diluted with charcoal-filtered air through a mass flowmeter to achieve 5 ppm V/v in the airstream to the chamber. Air was supplied through a Worthington air compressor; flow was measured with a Matheson #605 Flowmeter. Chamber concentrations were not directly measured for sulfur dioxide nor for any of the other gas treatments. Corrections for barometric pressure and air temperatures were made as needed. Flow rate was maintained at 1.77 ft^3/min (50 l/min) until symptoms appeared on the needles, about 6 hours later. Seedlings were then removed to the normal greenhouse environment.

HYDROGEN SULFIDE

Hydrogen sulfide was obtained from Matheson in a pressurized tank at 1.20 percent in helium. The gas was delivered to the seedlings at 50 ppm for 8 hours as described for SO_2.

ETHYL MERCAPTAN

Ethyl mercaptan was obtained from Matheson at 1.28 percent in pure nitrogen and administered to the plants for 10 hours at 50 ppm as described for SO_2.

HYDROGEN FLUORIDE

Hydrogen fluoride at 113 ppm in air was obtained from Matheson and delivered to the plants at 5 ppb as described for SO_2. Injury appeared within 3 hours and the seedlings were removed from the chamber to the normal greenhouse environment.

Symptomatic current-year needles from each of the treatments were collected within 2 weeks of injury. Specimens were killed and fixed in formalin-acetic-alcohol (FAA), dehydrated through tertiary butyl alcohol, and embedded in paraffin (Johansen 1940). Serial longitudinal and transverse sections of the entire transition zone were cut to 4.72×10^{-4} inch (12 microns) thickness on a rotary microtome, stained with a Feulgen's and fast-green schedule, and observed and photographed through a phase-contrast microscope. The transition zone is the more or less gradual boundary between and including green and necrotic needle tissue. Thus, the serial sections included necrotic, chlorotic, and green tissue. This is the region in which one would expect to observe developmental symptoms of internal injury to needle tissues and to have the greatest probability of noting differences between injuries caused by different agents.

Field Study

To determine whether conifer foliage in field situations developed symptoms similar to those observed in the laboratory study, representative necrotic needles of various ages were collected from trees near seven industries known to emit phytotoxic gases and from trees in two areas damaged by winter drying. Sampling locations, major abiotic agents, sample size, and species are shown in table 1.

Necrotic needles in fluoride-polluted ecosystems were collected near an aluminum plant at Columbia Falls, Mont.; near two aluminum plants in the Rhone Valley of Switzerland; and near a phosphorus plant at Ramsay, Mont. Conifer needle samples within sulfur dioxide-polluted areas were collected near a lead smelter at Helena, Mont., and a copper smelter at Anaconda, Mont. Needles presumably injured by hydrogen sulfide were collected near a geothermal complex in California. Conifer foliage injured by a complex of sulfur dioxide, hydrogen

Table 1.—Sampling locations, major abiotic agent, species, number of trees sampled, and age of sectioned needles of field-collected specimens

Major abiotic agents	Collection location	Species	Number of trees sampled	Age of sectioned needles
				Years
Hydrogen fluoride	Anaconda Aluminum Co., Columbia Falls, Mont.	*Pinus contorta*	20	2
		Pinus ponderosa	15	2
		Pseudotsuga menziesii	10	3
	Rhone Valley, Switzerland (aluminum production)	*Pinus sylvestris*	10	2
	Stauffer Chemical Co., Ramsay, Mont. (phosphorus production)	*Pinus contorta*	2	2
		Pinus ponderosa	2	2
Sulfur dioxide	ASARCO Lead Smelter, Helena, Mont.	*Pinus ponderosa*	6	2
	Anaconda Copper Smelter, Anaconda, Mont.	*Pseudotsuga menziesii*	1	3
		Pinus contorta	5	2
		Pinus flexilis	5	2
Hydrogen sulfide	Geothermal Complex, Geyserville, Calif.	*Pinus ponderosa*	4	2,3
Sulfur dioxide, hydrogen sulfide, methyl mercaptan complex	Hoerner-Waldorf Pulp and Paper Mill, Missoula, Mont.	*Pseudotsuga menziesii*	25	2,3
		Pinus ponderosa	5	2
Winter drying	Blackfoot Valley, NE of Missoula, Mont.	*Pinus ponderosa*	2	2
	East Glacier, Mont.	*Pinus contorta*	2	2

sulfide, and methyl mercaptan was collected near a pulp and papermill at Missoula, Mont. Specimens representing winter injury were collected in the Blackfoot Valley ca. 20 miles east of Missoula, Mont., and near East Glacier, Mont.

Presence of airborne phytotoxic gases near the industrial sources was assumed. The assumption was based on the publications cited below and on personal knowledge. Air samples were not taken for pollutant analysis at the time foliage samples were collected. Fluoride emissions from an aluminum plant in northwestern Montana were described by the State of Montana (1974). Wood (1968) discussed fluorides emitted by phosphorus manufacturing facilities and the release of sulfur dioxide from copper and lead smelting operations. Hydrogen sulfide released from geothermal energy production in California was described by Miller,[1] whereas reduced sulfurs from a pulp and paper mill in western Montana were documented by Berg and others (1973). Carlson and Meyer (1973) documented the occurrence of the winter injury episode in the Blackfoot Valley in western Montana.

Field-collected specimens were 2 to 3 years old because little necrosis was found on first-year needles, whereas current-year foliage was sampled in the laboratory study. The numbers of field-collected specimens sectioned and observed by causal agent were: fluoride, 64; sulfur dioxide, 16; reduced sulfurs, 30; winter damage, 4; and control, 20. All collected specimens were embedded, sectioned, and stained as described for the laboratory study.

[1] [illegible]

RESULTS AND DISCUSSION

Laboratory Study

Pinus ponderosa and *Pseudotsuga menziesii* responded nearly identically within treatments and the symptoms (responses to treatment) described below apply to both species. Unless otherwise stated, all observations in the laboratory study refer to the chlorotic region within the transition zone on current-year foliage. Figures 2 through 5 show macroscopic responses of both species to control and sulfur dioxide fumigations.

CONTROL

Needles remained green and healthy throughout the experiment (figs. 2, 4). Cells of all internal tissues appeared turgid and normal, with little or no plasmolysis caused by the histological procedures (fig. 6). Plastids were dispersed within the chlorenchyma and were not granulated (table 2 and fig. 7). Xylem cells were stained light pink and living cells light greenish-blue. Staining was normally differentiated with no obvious accumulation or intensification within the vascular tissues (fig. 8).

SALT

Needles showed symptoms of salt toxicity within 15 to 20 days following the initial treatment. Chlorosis appeared at the tip, middle, or base and was independent of species or individual. Usually the transition zone was diffuse, not distinct. In all cases, symptoms intensified until the trees were dead, even though fresh water replaced the salt treatments soon after the onset of symptoms. Mesophyll chlorenchyma plasmolyzed extensively and most plastids were destroyed (figs. 9, 10). Endodermal cells in the region of plasmolyzed mesophyll remained turgid and intact but xylem, phloem, and transfusion parenchyma collapsed (table 2). Phloem elements virtually disintegrated, and there was no obvious accumulation of stain within the transition zone (fig. 10).

DROUGHT

Chlorosis most often appeared first at the needle base and progressed acropetally. No distinct transition zone was formed. Mesophyll cells collapsed but did not plasmolyze as in the salt treatment (table 2). All other living cell types collapsed except the endodermis (fig. 11). No obvious accumulation of stain occurred within the transition zone.

WINTER DRYING

The syndrome for winter drying (table 2) was virtually the same as for drought except that injury appeared much sooner, within 3 to 5 days (figs. 12, 13).

SULFUR DIOXIDE

Chlorosis appeared near or at the tips within 3 to 8 hours following fumigation and an abrupt, distinct transition zone developed (figs. 3, 5). Sporadic collapse of the mesophyll occurred, and plastids clumped near the plasmalemma. Endodermis cells in contact with a necrotic mesophyll chlorenchyma collapsed (figs. 14, 15). Xylem, phloem, and transfusion parenchyma and phloem elements showed extensive hypertrophy and hyperplasia. Epithelial cells hypertrophied, occluding the resin canals (fig. 16). An intense, purple-red stain developed in the vascular tissues and extended basipetally into the region of nondamaged mesophyll (table 2).

HYDROGEN FLUORIDE, HYDROGEN SULFIDE, AND ETHYL MERCAPTAN

The internal syndrome induced by these pollutants was indistinguishable from that caused by SO_2 (table 2 and figs. 17–19). However, H_2S caused necrosis to only the needle tips, whereas F^- and C_2H_6S injury initially appeared slightly below the tips and progressed acropetally and basipetally. Also, tracheid cell walls were stained yellowish in needles injured by H_2S, unlike the light red in needles injured by the other gases.

Field Study

Control specimens were histologically similar to those of the laboratory study (fig. 20). Similarly, symptoms in the transition zones of field-collected needles within polluted areas were identical with symptoms induced by gaseous pollutants in the greenhouse study (figs. 23–28). Plastids clumped in the mesophyll parenchyma; endodermis collapsed when in contact with damaged mesophyll; and phloem, xylem, and transfusion parenchyma and epithelial cells divided excessively and became abnormally large. Resin ducts were occluded by the hypertrophy of epithelial cells. An intense purple-red stain developed in the vascular tissue extending well into the area of nondamaged mesophyll. The total syndrome was similar regardless of pollutant or species; for example, it was not possible to differentiate fluoride injury from SO_2, and all species and needle ages responded similarly.

Winter drying, however, was dissimilar to pollutant injury; this difference also was observed in the laboratory study. Mesophyll collapsed, endodermis remained turgid even when in contact with collapsed, necrotic mesophyll, and no hypertrophy or hyperplasia occurred in the parenchyma (figs.21, 22). Epithelial cells in winter-dried specimens were hypertrophied, often occluding the resin canals. No intense stain developed in the vascular cylinder such as occurred with gas-injured specimens; the symptoms were similar among the different species and needles of various ages.

Histological differentiation of needle necrosis has not been clearly defined. Solberg and others (1955) and Solberg and Adams (1956) showed that HF and SO_2 disrupted vascular tissues and caused hypertrophy and hyperplasia of vascular parenchyma. They indicated that HF injury could be distinguished from SO_2. Evans and Miller (1972, 1975) stated that SO_2, suspected winter injury, and ozone injury could be distinguished histologically in that SO_2 disrupted and dissolved cytoplasmic constituents of all needle tissues, whereas ozone injured only the plicate parenchyma and winter fleck caused abnormalities within the phloem and transfusion cells. Their sections were taken adjacent to necrotic lesions and not within a transition zone as described in this paper. Also, their winter injury was suspected to be direct cold injury and not of the drying type. Stewart and others (1973) were not able to distinguish between symptoms of SO_2, HF, and winter injury. They observed hypertrophy of phloem cells and mesophyll parenchyma cells when natural senescence, drought, and fluoride were causes of necrosis. Consequently, Stewart and others (1973) saw little value in the use of histological interpretations to differentiate among various environmental stresses. Conversely, biotic causes usually are easily diagnosed histologically by signs of the causal organism.

Table 2.—Qualitative comparison of experimentally induced abiotic stresses on various *Pseudotsuga menziesii* and *Pinus ponderosa* needle tissues[1]

Treatment	External symptomatology	Mesophyll	Endodermis	Transfusion parenchyma	Xylem parenchyma	Phloem	Phloem parenchyma	Epithelial cells	Staining pattern, in vascular tissue
Control	Needles remained deep green	Fully turgid, plastids not clumped, dispersed	Intact, turgid	Turgid	Turgid	Turgid	Turgid	Turgid	[illegible]
Salt, 12,000 ppm in tapwater	Chlorosis of base, middle, or tip within 15–20 days, zone between necrotic and green tissue not distinct	Extreme plasmolysis, chloroplasts destroyed	Inact, turgid	Collapsed	Collapsed	Disintegrated	Collapsed	Collapsed	Normal, no particular concentration of stain
Drought, water withheld	Chlorisis and necrosis within 15–25 days, often progressing acropetally from base. Diffuse, no distinct banding Needles twist	Collapsed, but not plasmolyzed	Intact, turgid	Collapsed	Collapsed	Collapsed	Collapsed	Collapsed	Normal, no particular concentration of stain
Winter drying, roots frozen, 25–30°C, slight breeze	Same as drought, but injury occurs within 3–5 days	Collapse	Intact, turgid	Collapsed	Collapsed	Collapsed	Collapsed	Collapsed	Same as Salt and Drought
Sulfur dioxide, 5 ppm	Chlorosis at tips or slightly proximal to tip within 3–8 h, abrupt transition between green and chlorotic tissue	Clumping of plastids, some collapse	Collapsed where mesophyll is necrotis	Hypertrophy and hyperplasia	Hypertrophy and hyperplasia	Hyper trophy, hyperplasia, & collapse	Hypertrophy and hyperplasia	Hyper trophied occluding resin canal	Intense purple-red and purple-blue extending basipetally into area of non-damaged mesophyll
Fluoride, 5 ppb	Chlorosis slightly below tips within 5–6 h, progressing acropetally Abrupt transition zone	Clumping of plastids, little collapse	Collapsed where mesophyll is necrotic	Hypertrophy and hyper plasia	Hypertrophy and hyperplasia	Hyper trophy and hyper plasia	Hypertrophy and hyperplasia	Hyper trophied, resin canals occluded	[illegible]
H_2S, 50 ppm	Well defined tip chlorosis within 20 h, necrosis limited to tips, transition zone abrupt	Same as SO_2, HF	Same as SO_2, HF	Same as SO_2 and HF	Same as SO_2 and HF	Same as SO_2 and HF	Same as SO and HF	Same as SO_2 and HF	[illegible] cell walls, intense purple-red [illegible] extending basipetally into area of non-damaged mesophyll
C_2H_6S, 50 ppm	Tip chlorosis within 20–15 h, transition zone abrupt	Same as SO_2, HF	Same as SO_2 and HF	Same as C_2H_6S and HF	Same as SO and HF	[illegible] SO_2 and HF	[illegible] and HF	[illegible] SO_2 and HF	[illegible] and HF

[1]All observations were made within the transition zone, a 2 mm segment including the necrotic, chlorotic, and green portions of injured needle Generally, the transition zone is chlorotic.

[2]Feulgen's and fast green schedule

Figure 2.—Lab study. Control ponderosa pine seedling after treatment with clean air in fumigation chamber. Current-year foliage remained green; no necrosis or chlorosis was observed.

Figure 3.—Lab study. Ponderosa pine seedling after treatment with 5 ppm SO_2 for 6 hours. All current foliage developed necrosis.

Figure 4.—Lab study. Control Douglas-fir seedling. Similar to ponderosa pine, current-year foliage remained green and appeared healthy.

Figure 5.—Lab study. Douglas-fir foliage after fumigation with 5 ppm SO_2 for 6 hours. Note the well-defined tip necrosis. Needle segments for histological study were taken from the transition zone, which included green, chlorotic, and necrotic tissue. Serial longitudinal and transverse thin sections 4.72×10^{-4} in (12 microns) thick then were made through the entire transition zone. Histological interpretations were made from these sections.

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6.—Lab study. Control, ponderosa pine, longitudinal section, X300. Endodermis (EN), vascular parenchyma (VP), phloem (P), and xylem (X) are fully turgid. Hypertrophy and hyperplasia of parenchymatous tissue have not occurred here, but do in needles affected by phytotoxic gases. Current-year foliage.

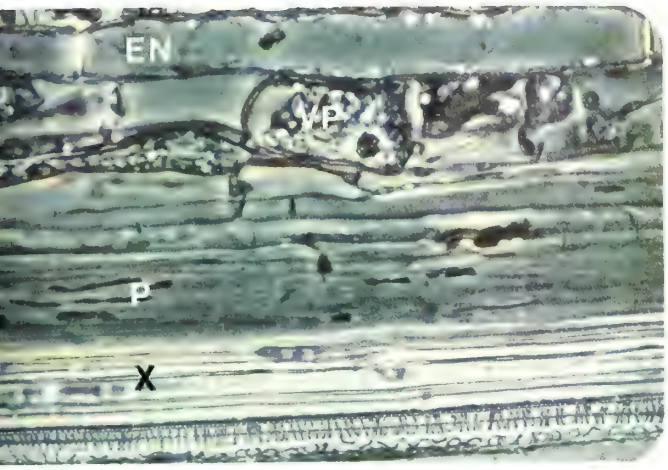
Figure 7.—Lab study. Control, ponderosa pine, transverse section, X300. Note position of epidermis (ED), hypodermis (HY), mesophyll parenchyma (MP), and resin canal (RC). Presence of numerous dispersed plastids in turgid mesophyll cells and nonhypertrophied epithelial cells (EP) in the resin canal are indicative of a healthy needle. Current-year foliage.

Figure 8.—Lab study. Control, ponderosa pine, transverse section, X300. Note position of phloem (P), vascular parenchyma (VP), xylem (X), endodermis (EN), and mesophyll (MP). Endodermis is turgid and phloem and vascular parenchyma are not deeply stained nor hypertrophied. Mesophyll is turgid and packed with plastids. Current-year foliage.

Figure 9.—Lab study. Salt injury, ponderosa pine, longitudinal section, X300. Mesophyll parenchyma (MP) collapsed, but the endodermis (EN) remained turgid even when in contact with necrotic mesophyll cells. Note the junction between necrotic mesophyll and healthy endodermis (arrow). Current-year foliage.

Figure 10.—Lab study. Salt injury, ponderosa pine, transverse section, X300. This section is from the necrotic portion of the transition zone. Parenchymatous tissues including mesophyll (MP), vascular parenchyma (VP), and phloem (P) collapsed. Even in this condition of extreme injury, the endodermis (EN) is, for the most part, somewhat turgid. Current-year foliage.

Figure 11.—Lab study. Drought, ponderosa pine, longitudinal section, X300. Mesophyll (MP) collapsed but endodermis (EN) in contact with necrotic mesophyll remains turgid. Current-year foliage.



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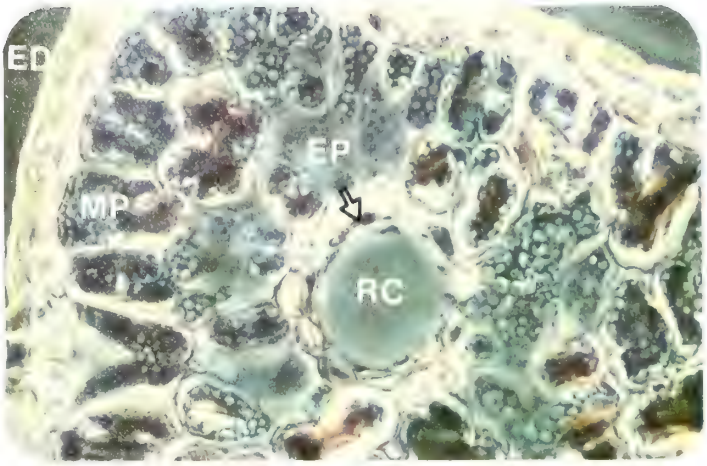
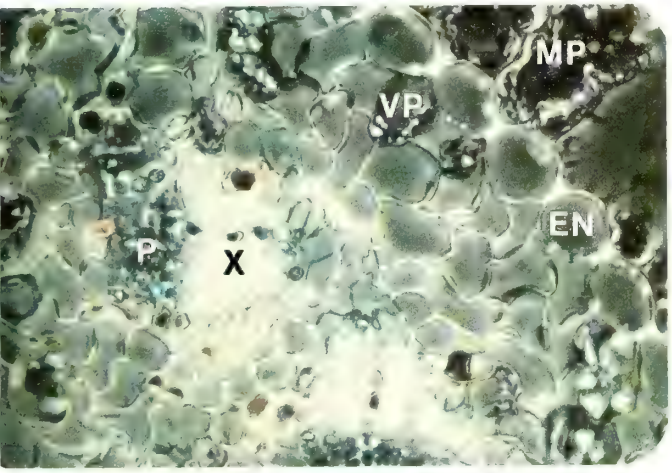


Figure 7



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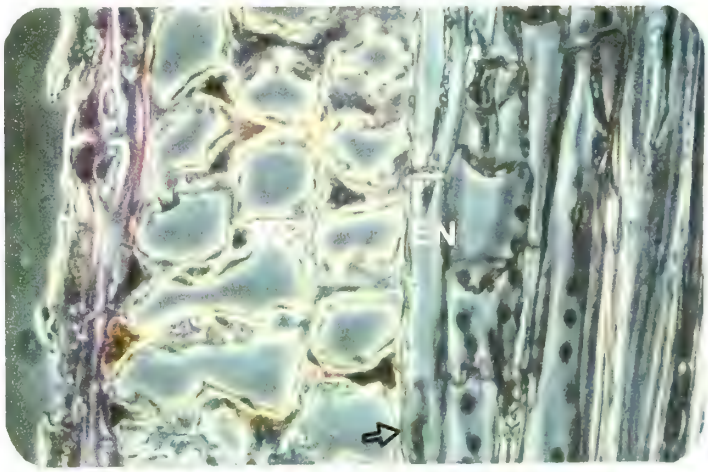

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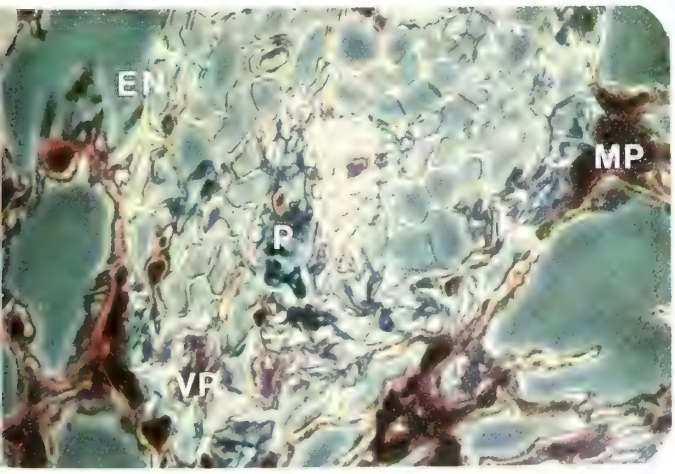

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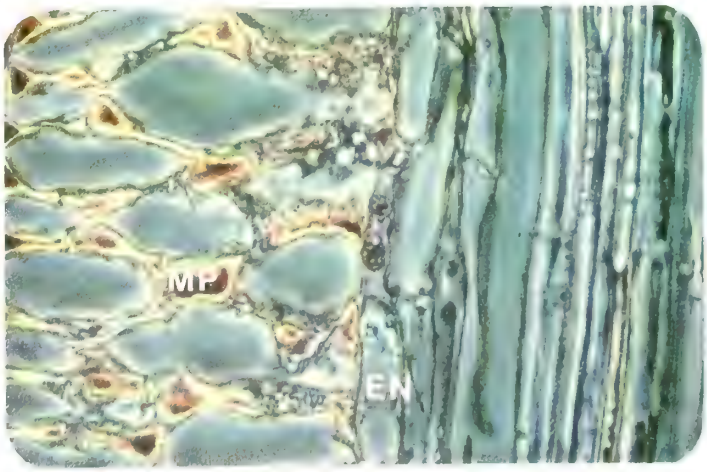


Figure 11

Figure 12.—Lab study. Winter drying, ponderosa pine, longitudinal section, X300. Mesophyll (MP) collapsed, but endodermis (EN) remained turgid. Note similarity between injury by salt, drought, and winter drying (figs. 9–12). Current-year foliage.

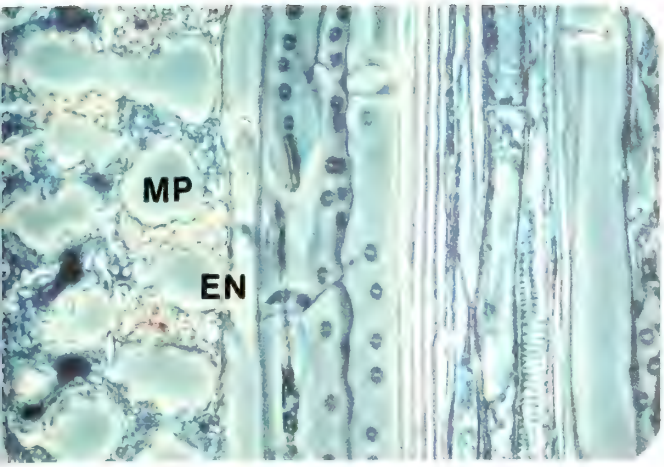
Figure 13.—Lab study. Winter drying, ponderosa pine, transverse section, X300. Mesophyll (MP), vascular parenchyma (VP), and phloem (P) collapsed while endodermis remains turgid. No deep staining occurred in the vascular tissues. Current-year foliage.

Figure 14.—Lab study. Sulfur dioxide, ponderosa pine, longitudinal section, X300. Mesophyll (MP) collapsed and endodermis (EN) in contact with collapsed necrotic mesophyll also collapsed. Note the intense reddish staining in the vascular bundle (within the endodermis) extending basipetally into the region of noninjured mesophyll. Note the hypertrophy (excessive cell enlargement [HT]) and hyperplasia (excessive cell division [HP]) that occurred in the vascular parenchyma, causing the vascular bundle to swell. These three symptoms, endodermis collapse, intense vascular stain, and swelling, are characteristic of injury induced by phytotoxic gas, but not by other causes. Compare with salt, drought, and winter drying (figs. 9–13). Current-year foliage.

Figure 15.—Lab study. Sulfur dioxide, ponderosa pine, transverse section, X300. This section is from the green end of the transition zone. Vascular parenchyma (VP) hypertrophied and the characteristic deep reddish stain pervaded the vascular tissues. Mesophyll (MP) has not collapsed. Phloem (P) has been destroyed. Current-year foliage.

Figure 16.—Lab study. Sulfur dioxide, ponderosa pine, transverse section, X300. Epithelial cells (EP) hypertrophied and occluded the resin canal (RC). Mesophyll (MP) is not noticeably affected. Hypertrophy of epithelial tissue commonly occurs in needles injured by phytotoxic gases, but also is found in needles injured by winter drying and drought. It is not distinctive for phytotoxic gases. Current-year foliage.

Figure 17.—Lab study. Hydrogen sulfide, ponderosa pine, longitudinal section, X300. Collapsed endodermis (EN), deep-red vascular staining, and hypertrophy of vascular parenchyma (VP) are evident. These symptoms are similar to those caused by SO_2. Current-year foliage.



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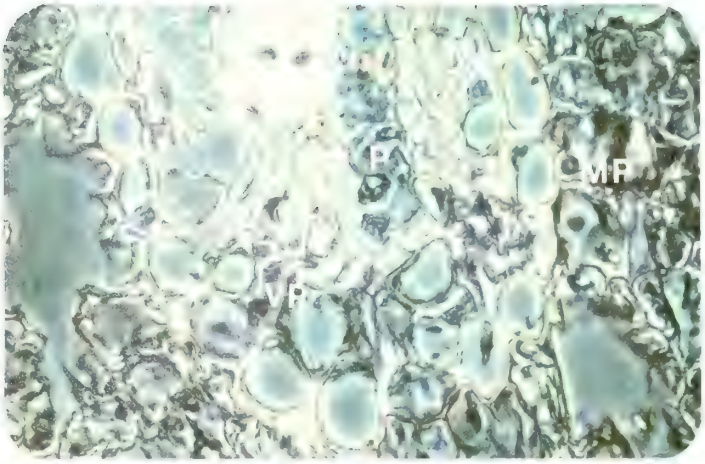

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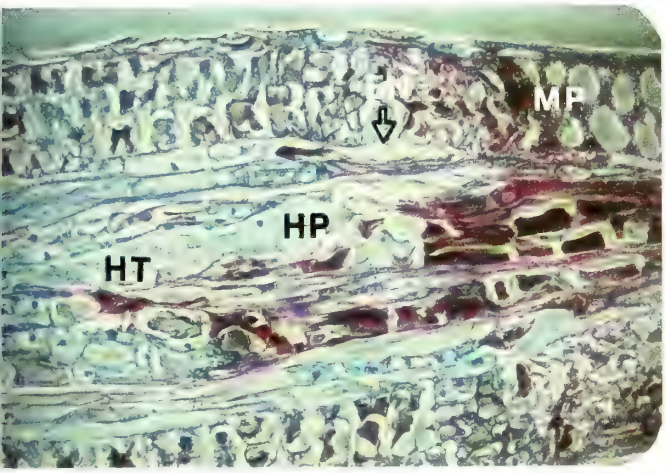

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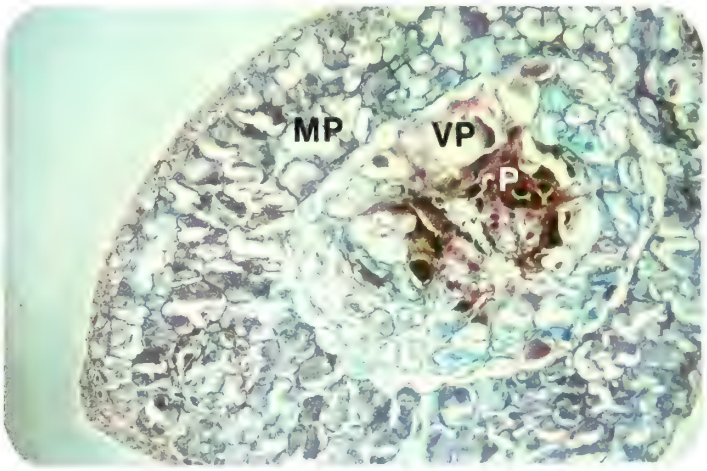

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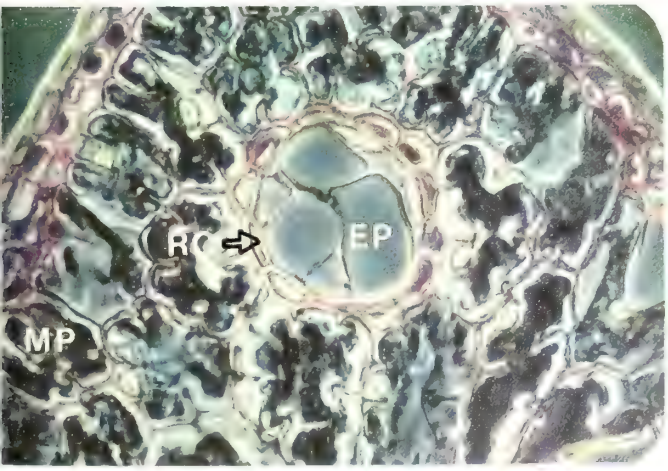

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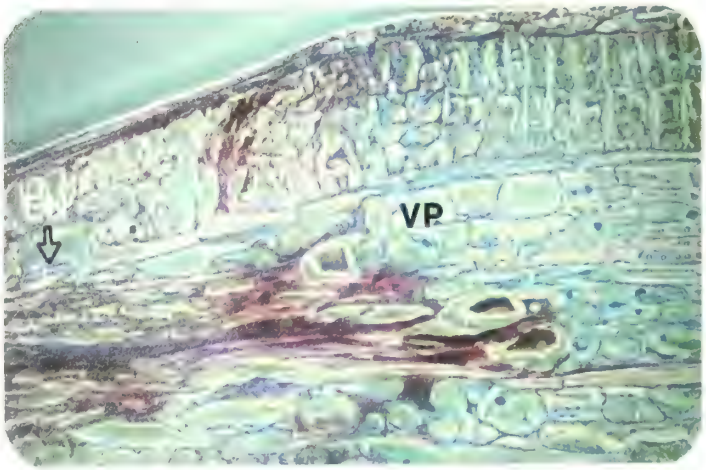


Figure 17

Figure 18.—Lab study. Ethyl mercaptan, ponderosa pine, longitudinal section, X300. Symptoms are similar to those caused by sulfur dioxide. Note hypertrophied vascular parenchyma (VP), intense reddish staining in vascular bundle, and endodermis (EN) collapse in contact with necrotic mesophyll (MP). Current-year foliage.

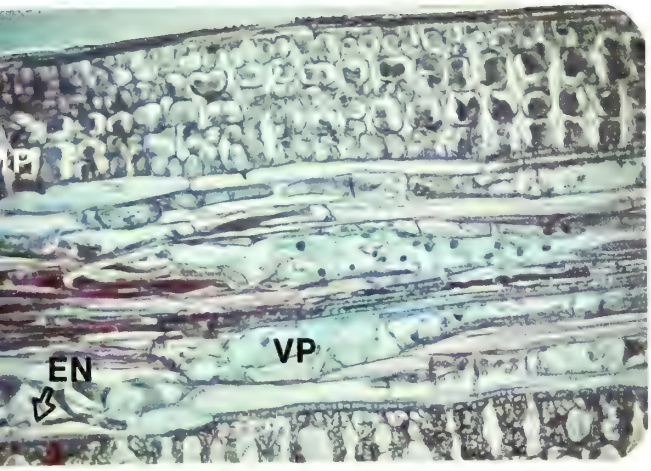
Figure 19.—Lab study. Hydrogen fluoride, Douglas-fir, longitudinal section, X300. Note collapse of endodermal cell (EN) in contact with necrotic mesophyll (MP). Also, the vascular bundle is deeply stained. Symptoms are similar to those caused by sulfur dioxide, hydrogen sulfide, and ethyl mercaptan in ponderosa pine needles. Compare with figures 14–18. In this experiment, the different symptoms induced by various treatments in ponderosa pine needles were identical to those induced in Douglas-fir needles. Current-year foliage.

Figure 20.—Field study. Control, ponderosa pine, transverse section, X125. Note position of mesophyll (MP), endodermis (EN), phloem (P), xylem (X), and vascular parenchyma (VP). The only difference between this needle and the control needle of the lab study (fig. 8) is that the phloem and xylem are better developed. All needles shown for field study were 2 years old.

Figure 21.—Field study. Winter drying, ponderosa pine, longitudinal section, X25. Note position of epidermis (ED), mesophyll (MP), resin canal (RC), endodermis (EN), vascular parenchyma (VP), phloem (P), and xylem (X). The collapsed mesophyll (arrow) identifies the necrotic part of the needle. No intensive, reddish staining occurred in the vascular bundle nor did transfusion parenchyma undergo hypertrophy and hyperplasia.

Figure 22.—Field study. Winter drying, ponderosa pine, longitudinal section, X125. Note collapsed mesophyll (MP). Endodermis (EN) in contact with collapsed mesophyll is turgid, healthy, and vascular parenchyma (VP) is normal. This section included some epithelial (EP) tissue that also appears normal.

Figure 23.—Field study. Sulfur dioxide, ponderosa pine, longitudinal section, X25. Deeply stained vascular tissue (VT), collapsed mesophyll (MP), and necrotic endodermal cells (EN) occurred. This is similar to specimens injured by sulfur dioxide in the lab study.



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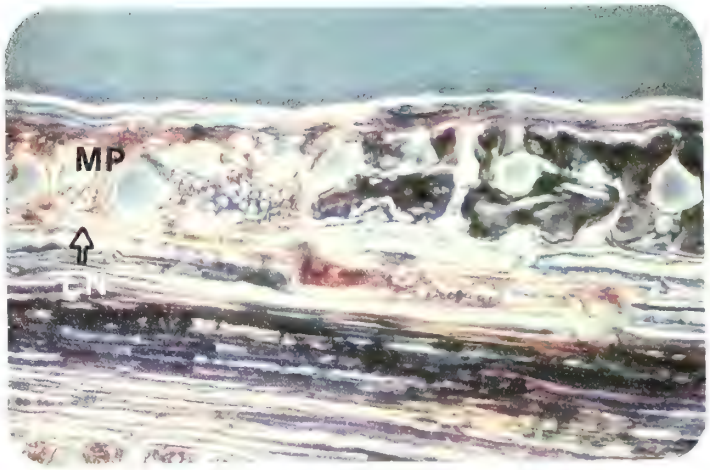

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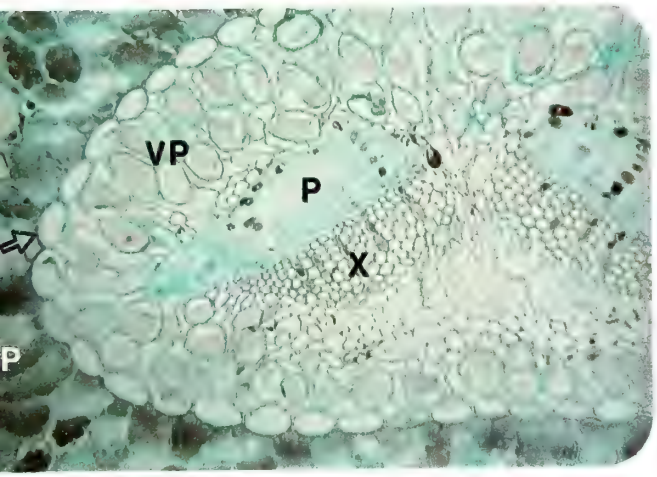

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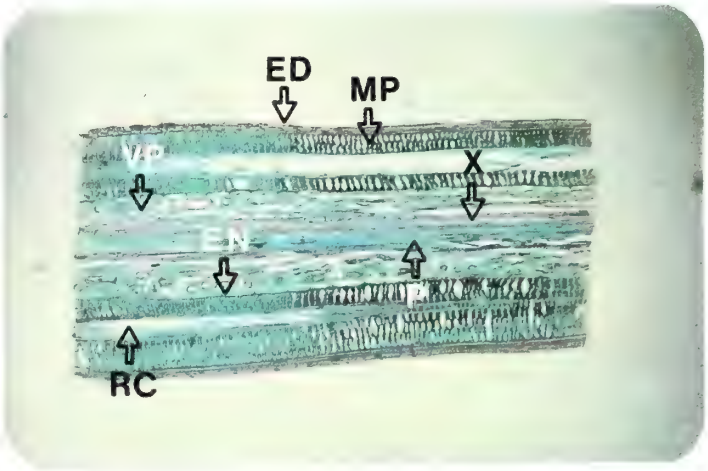

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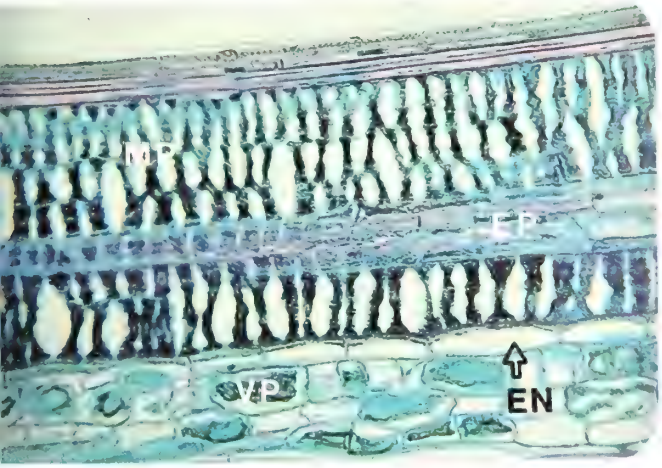

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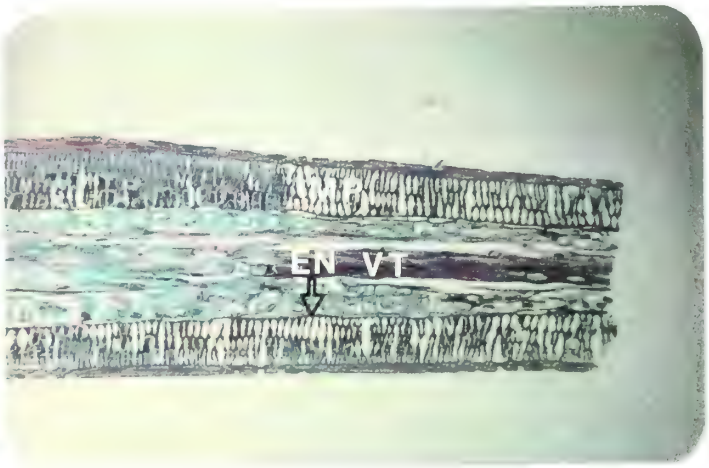


Figure 23

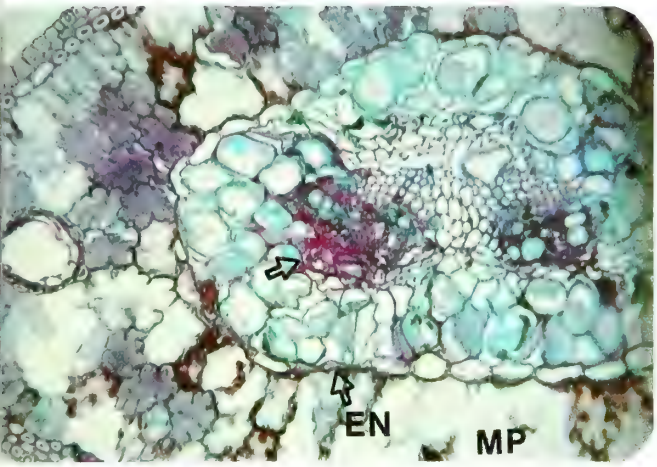
Figure 24.—Field study. Sulfur dioxide, ponderosa pine, transverse section, X125. Deep reddish stain (arrow) and necrotic endodermis (EN) in contact with necrotic mesophyll (MP) typify injury by phytotoxic gases.

Figure 25.—Field study. Hydrogen sulfide, ponderosa pine, longitudinal section, X125. Note necrotic endodermis (EN), intense stain in vascular tissue (VT), and hypertrophy of vascular parenchyma (VP).

Figure 26.—Field study. Hydrogen sulfide, ponderosa pine, transverse section, X125. This section is from the greenish portion of the transition zone. Note destruction and heavy staining in the vascular tissues (VT). Note also the hypertrophy and hyperplasia in the vascular parenchyma (VP).

Figure 27.—Field study. Hydrogen fluoride, Scotch pine, longitudinal section, X125. These specimens were obtained from the Rhone Valley in Switzerland. Characteristic of injury caused by fluoride and other phytotoxic gases, endodermal cells (EN) in contact with necrotic mesophyll (MP) are necrotic, the vascular cylinder (VC) is deeply stained, and vascular parenchyma (VP) has hypertrophied. Compare with figures 14 through 19 and 23 through 26.

Figure 28.—Field study, hydrogen fluoride, Scotch pine, transverse section, X125. This specimen also is from the Rhone Valley in Switzerland. The section was cut in the greenish portion of the transition zone. Notice the deep staining of vascular parenchyma (VP).



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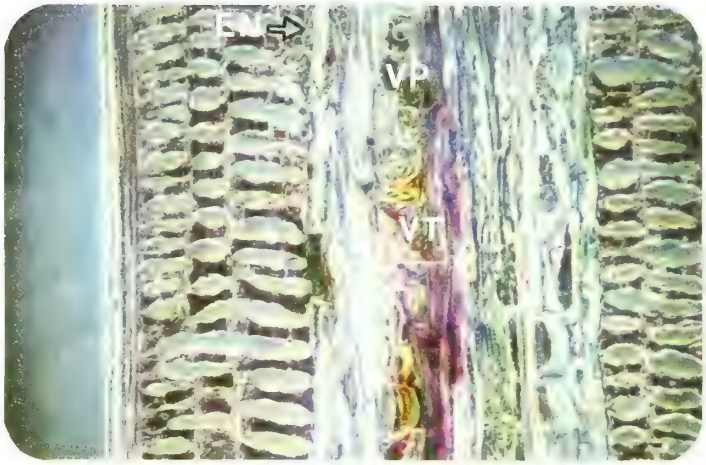

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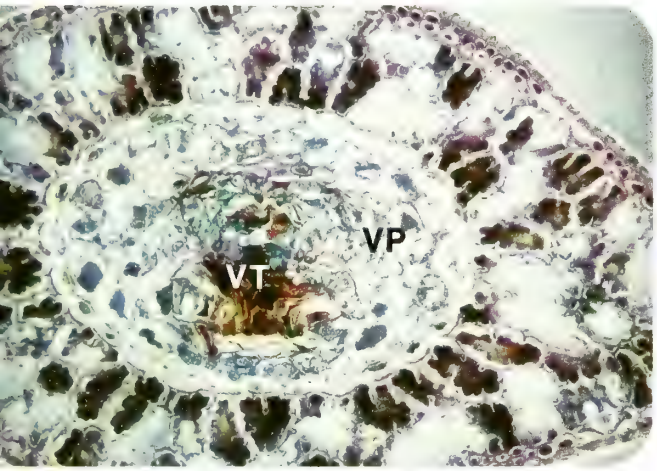

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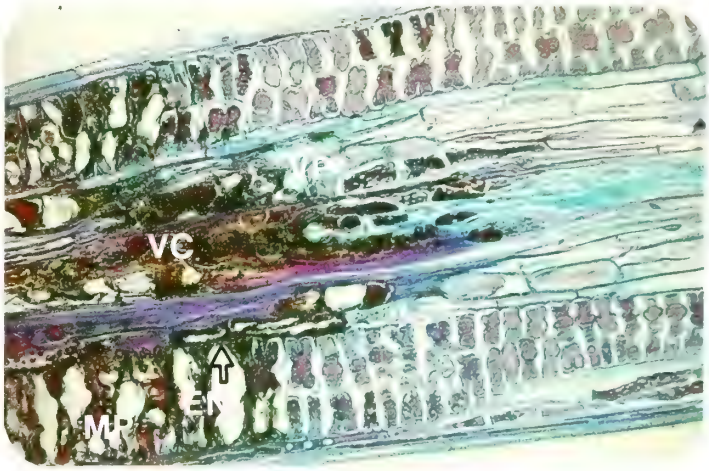

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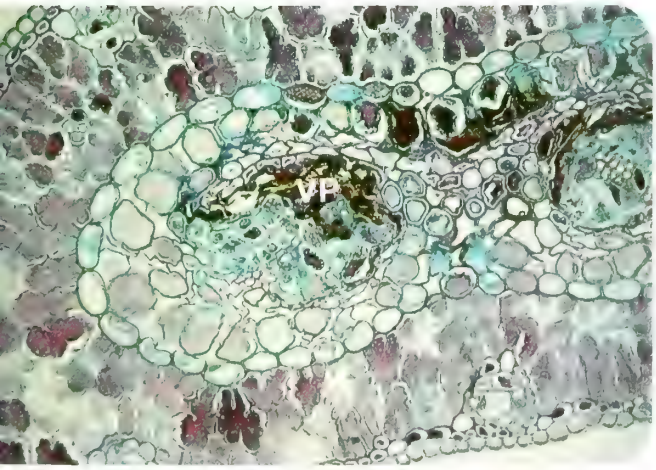

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Our studies show that needle necrosis caused by phytotoxic gases can be differentiated microscopically from necrosis caused by other abiotic agents. The controlled greenhouse study showed that symptoms of gas-caused needle necrosis can be distinguished from symptoms of selected nongaseous causes. Phytotoxic gases caused extensive damage to parenchymatous tissues, especially within the vascular system, but it was not possible to distinguish among symptoms caused by various gases. Winter drying and drought caused mesophyll damage, but the tissues of the vascular system were not affected. Endodermal cells in contact with necrotic mesophyll became necrotic when phytotoxic gas was the cause, but not when damage was induced by winter drying or normal drought; necrotic endodermal cells could result from acid hydrolysis. The mechanisms of endodermis susceptibility to phytotoxic gas, but resistance to winter damage, salt, and drought is biologically interesting and should be investigated. The deep staining of vascular tissue in the transition zone noted in the gas fumigations could have been induced by cytoplasmic dissolution. Evans and Miller (1975) noted that sulfur dioxide decreased the intensity of stain where cytoplasmic dissolution was extensive. We observed the same in the necrotic areas. However, in the chlorotic part of the transition zone, leakage of cytoplasmic contents from lysed cells into the intercellular spaces could account for the general deep staining observed in our study.

The histological interpretations of field-collected specimens were similar to those of the laboratory investigation; specimens collected from Switzerland, Montana, and California near known sources of phytotoxic gases exhibited the pollutant syndrome, but it was not possible to distinguish between pollutants. Winter-induced needle necrosis collected from areas of known winter drying was similar histologically to the laboratory-induced winter drying. Studies by EPA (1971), Gordon (1972), Gordon and Tourangeau (1975), Carlson and Dewey (1971), Carlson and others (1974), and Gordon and others (1976) support these findings. In studies with tip-burned field-collected Austrian pine needles, Maiello and others (1972) determined that sulfur dioxide caused distortion of endodermis and transfusion tissues and that this disruption of vascular tissues extended about 0.02 in (0.5 mm) into the region of healthy mesophyll. Results of our studies agree.

Solberg and Adams (1956), Gordon (1972), and Gordon and Tourangeau (1975) believed they could distinguish between injury caused by sulfur oxides and fluoride. Vascular tissues were disrupted in the area of healthy and necrotic mesophyll when fluoride was causal, whereas vascular tissues appeared normal even in the region of necrotic mesophyll when sulfur dioxide was the agent. We did not observe this either in the controlled fumigation or in the field-collected specimens. It seems unlikely that plant tissues would have separate response syndromes to individual gases. However, it is plausible that responses would differ between such different agents as gases versus drought or salt, as suggested by our work.

The simulated winter injury treatment subjected physiologically active, succulent young needle tissue to relatively severe stress. Natural winter drying occurs to older foliage (8 to 10 months) that likely is in a subdued physiological state. Thus, the simulated treatment can be interpreted as severe. However, notwithstanding these treatment differences, the histological effects of field- and laboratory-induced stress were similar, indicating similarity between physiological and morphological responses.

The gases were administered at high concentrations, presumably much higher than one would expect to find in field situations. Also, the gas concentrations were not monitored in the exposure chamber, but were inferred from flow input. We were not interested in testing effects of differential gas concentrations; rather, we wished to assure the development of needle necrosis and to compare between treatments. Histological reactions to our dosages may represent responses only to short-term acute fumigations and may not be representative of actual field situations. However, histological symptoms in field-collected specimens were similar within treatment to those in needles with experimentally induced necrosis. It is likely, but not known, that necrosis on needles from field locations was caused by longer-term, lower concentration of pollutant. If so, the continuity between symptoms observed in field and laboratory specimens suggests that the histological reactions represent a biochemical-morphological reaction not entirely dependent on gas concentration.

Our field study did not include either drought- or salt-caused needle necrosis. However, there is little reason to believe that field-induced symptoms would differ significantly from our greenhouse work.

Finally, the concept that needle necrosis caused by phytotoxic gases can be separated from other selected abiotic agents is well supported in that differences observed in the laboratory experiment also were observed in corresponding field collections.

SUMMARY AND CONCLUSIONS

Phytotoxic gases cause histological symptoms in Douglas-fir and ponderosa pine needles distinct from those induced by winter damage, drought, or salt. The symptoms caused by gaseous pollutants under controlled conditions are:

1. Collapse of endodermis in contact with collapsed mesophyll.
2. Hypertrophy and hyperplasia of vascular parenchyma.
3. Deep staining of vascular tissue, extending basipetally into the region of healthy mesophyll.

Winter damage, drought, and salt induce the following symptoms:

1. Mesophyll cells collapse, but endodermis is not affected, even when in contact with necrotic mesophyll.
2. Vascular parenchyma collapse; hypertrophy and hyperplasia are not evident.
3. Deep staining of vascular tissues does not occur.

Symptoms in field-collected specimens representative of a variety of conifers were similar for similar causal agents.

Identification of the cause of conifer injury and related forest damage near sources of phytotoxic air emissions may be confounded by insects, disease, weather, or other abiotic agents. Affected trees usually exhibit foliar chlorosis and necrosis in response to causal factors. This study demonstrates that through histological procedures these causal factors may be distinguished. When used in conjunction with ambient air quality data, emission data, foliar chemical analyses, and observations of the status of biotic plant pathogens and foliage-feeding insects, histological observations should strengthen the diagnosis of cause in damage surveys done near polluting industries.

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Symptoms induced by phytotoxic gases within conifer needles can be differentiated histologically from those caused by other abiotic agents including winter drying, drought, and salt. However, it is not possible to differentiate among symptoms caused by hydrogen fluoride, sulfur dioxide, ethyl mercaptan, and hydrogen sulfide. Phytotoxic gases cause hypertrophy and hyperplasia of vascular parenchyma, endodermis collapse, and intense vascular staining. The other abiotic agents induce mesophyll collapse with little or no observable effects on vascular tissues. Histological analyses should be useful in diagnosis of air pollution-induced injury and damage in coniferous forests.

KEYWORDS: phytotoxic gases, winter injury, conifer needles, symptoms, histology, air pollution, diagnosis, needle necrosis

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RESEARCH SUMMARY

Various operational parameters were measured on actual retardant dropping missions using an instrumented S2F airtanker. The variables included drop height, drop configuration and tank release sequence, delay time, indicated airspeed, minimum height above fuel, and various use characteristics. The interpretatio of real-time operational data was investigated and the importance of various factors determined. Results cor firmed the validity of aircraft evaluation procedures ar instrumentation. Drop heights measured during actual operations support guidelines and general assumptior made in previous studies.

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Measurements of Airtanker Drop Conditions During Firefighting Operations

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INTRODUCTION

Aircraft drop height, speed, attitude, and other factors can drastically affect the distribution and effectiveness of retardant dropped from airtankers. Numerous studies have attempted to evaluate operationally the relative influence of factors such as type of retardant, aircraft, tank and gating system, and firefighting strategy. The studies have usually been inconclusive due to the large number of variables (many interacting), the magnitude of the effect of these variables, and the difficulty in quantifying the overall effectiveness of the retardant application (change in fire behavior, etc.). Guidelines derived from controlled tests are often not fully accepted, mainly because of lack of operational verification and disbelief in comparability of test conditions and field conditions.

The tank and gating system, volume of retardant dropped, drop configuration (number and position of compartments released), release sequence and interval, retardant type, wind, and aircraft height, speed and attitude may strongly affect retardant distribution. Many of these variables have been difficult to measure and have often been ignored in past studies.

Fire management economists, air attack specialists, chemical engineers, equipment design engineers, firefighters, and others are demanding more precise descriptions of drop conditions, tank and gating performance, and retardant distribution.

PREVIOUS RESEARCH

Many drop tests have been conducted to evaluate various aspects of retardant delivery and tank and gating system performance (Davis 1959; Johansen and Shimmel 1967; George and Blakely 1973; Grigel and others 1974). The drop conditions (drop height above ground and drop speed) were estimated from readings taken by the pilot or copilot, from measurements using a ground-based theodolite and timing devices, or determined from photographs of the drops. Although aircraft height and speed have often been estimated with good precision, relatively small changes (± 25 ft [7.6 m]) in drop height are known to alter drop patterns significantly (George 1975; Swanson and others 1978), especially at drop heights where total retardant breakup is incomplete (100 to 300 ft [30.5 to 91.4 m], depending on the tank and gating system and load size). Utilizing high-speed cameras equipped with electronic timing devices and analyzing the films using sophisticated motion analysis equipment, greater accuracy in measurements of drop conditions under controlled conditions has been achieved (George and Blakely 1973; George 1975).

Although drop conditions have been measured in various ways and with different degrees of accuracy, a continuing question has been whether the conditions (especially drop heights) used in specific drop studies are actually representative of conditions during operational use. Drop height estimates from firefighting personnel on the ground and air attack specialists have typically been lower than values determined photographically or by other means. Such estimates frequently have been lower than specified; for instance, the 150-ft (45.7-m) above-tree canopy safety minimum established by the USDA Forest Service. Although observers have disagreed as to whether estimates were "above ground"—"above fuel or canopy"—determining drop height for analysis or study has been controversial.

The effect of aircraft speed on retardant distribution over the range of drop speeds normally encountered (120 to 160 knots [61.7 to 82.3 m/s]) has been found to be significantly less than the effect of drop height (George 1975; Swanson and others 1976, 1978). Increasing air-

craft velocity with respect to the ground has been shown to generally reduce peak pattern coverage values and increase low coverage lengths. On-board aircraft velocity-indicating devices, however, provide an airspeed that is often at variance with ground speed because of wind. In addition to affecting airspeed, the wind velocity profile and the orientation of the aircraft to existing winds can significantly affect the retardant delivery. Although wind affects the dispersion of retardant, its primary influence is to displace the retardant cloud and pattern, and thus affect accuracy.

The number of tanks released on each pass and the interval between gate openings has been a primary method of controlling the retardant distribution. The volume of retardant for a simultaneous tank release and the sequence or time interval between consecutive tank releases has often been used to create the desired retardant pattern for a fuel/fire situation or to cope with specific drop conditions (terrain, wind, or other factors). During retardant evaluations other than under highly structured or controlled studies, the drop configuration—especially the sequential drop delay times—has not always been readily available or measurable.

Other factors known to influence ground pattern distributions to a lesser but sometimes significant degree are the aircraft attitude or "g" force on the wing at release (dive, bank, or loft mode) and the topography. Although the importance of these factors has been difficult to measure, their effects have been sufficiently determined for the needs of retardant distribution studies by the previous research discussed and empirical observations.

STUDY DESCRIPTION

The purpose of the study was (1) to identify methods that can be used to more thoroughly determine the conditions under which fire retardants are dropped operationally, and (2) to collect data that would substantiate or better define the operational use envelope. The study was conducted at Hemet, Calif., in cooperation with the California Department of Forestry (CDF). About 2.5 million gallons (9.5 million liters) of fire retardant are delivered annually to fires on both State of California and National Forest land from the Hemet Air Attack Base. Study objectives were to instrument one of the CDF airtankers, an S2F, and collect specific data during drops, along with general information regarding the type of drop, the target, fuel, and surrounding terrain. The S2F (Tracker), originally built by Grumman Aircraft Co. as a carrier-based antisubmarine aircraft, was modified to carry 800 gallons (3 028 liters) of retardant in four compartments containing approximately 200 gallons each. The particular S2F selected for the study (Tanker 73, N406DF) contained an "Aero-Union" type tank whose characteristics and performance have been quantified in the Airtanker Performance Guides (Swanson and others 1976).

INSTRUMENTATION AND PROCEDURES

Drop height

A pulse radar altimeter system (Honeywell Model 76 was selected to provide a continuous record of drop height. The system is composed of a receiver/transmitt two antennas, and a height indicator. In addition to pro ing high resolution, the altimeter produces leading edg tracking for actual distance between the aircraft and th nearest terrain or obstacle with an accuracy of 3 ft (0.9 ± 2 percent. The receiver/transmitter, designed for integral use in military or commercial aircraft, provides a output that can be continuously recorded.

The radar altimeter antennas require mounting appro mately 3 ft (0.9 m) apart on a level area of the aircraft sk free from disruption and protuberances and from whee interference. This was accomplished on the S2F by mo ing the antennas on the bottom side of the right wing a distance from the fuselage (fig. 1).

Figure 1.—Radar altimeter antennas mounted on the underside of the wing of a California Department of Forestry S2F airtanker.

Because drop height only during the actual drop was desired, an adjustable timer was provided to shut off th recording device after a preset time. An arming switch mounted within easy reach of the pilot so that prior to a drop, the recorder could be started. This provided a con uous trace of drop height until the recorder was automa ically shut off. This procedure minimized the additiona amount of attention needed by the pilot to operate the system.

A high-speed, fast-response strip chart recorder (Gou Brush Model 260) was used to record the drop height. T recorder had six channels and contained built-in event markers to provide a method of recording additional pa rameters and events (discussed later). A simplified sch matic of the on-board instrumentation, including the ra altimeter/drop height-measuring system, is shown in figure 2.

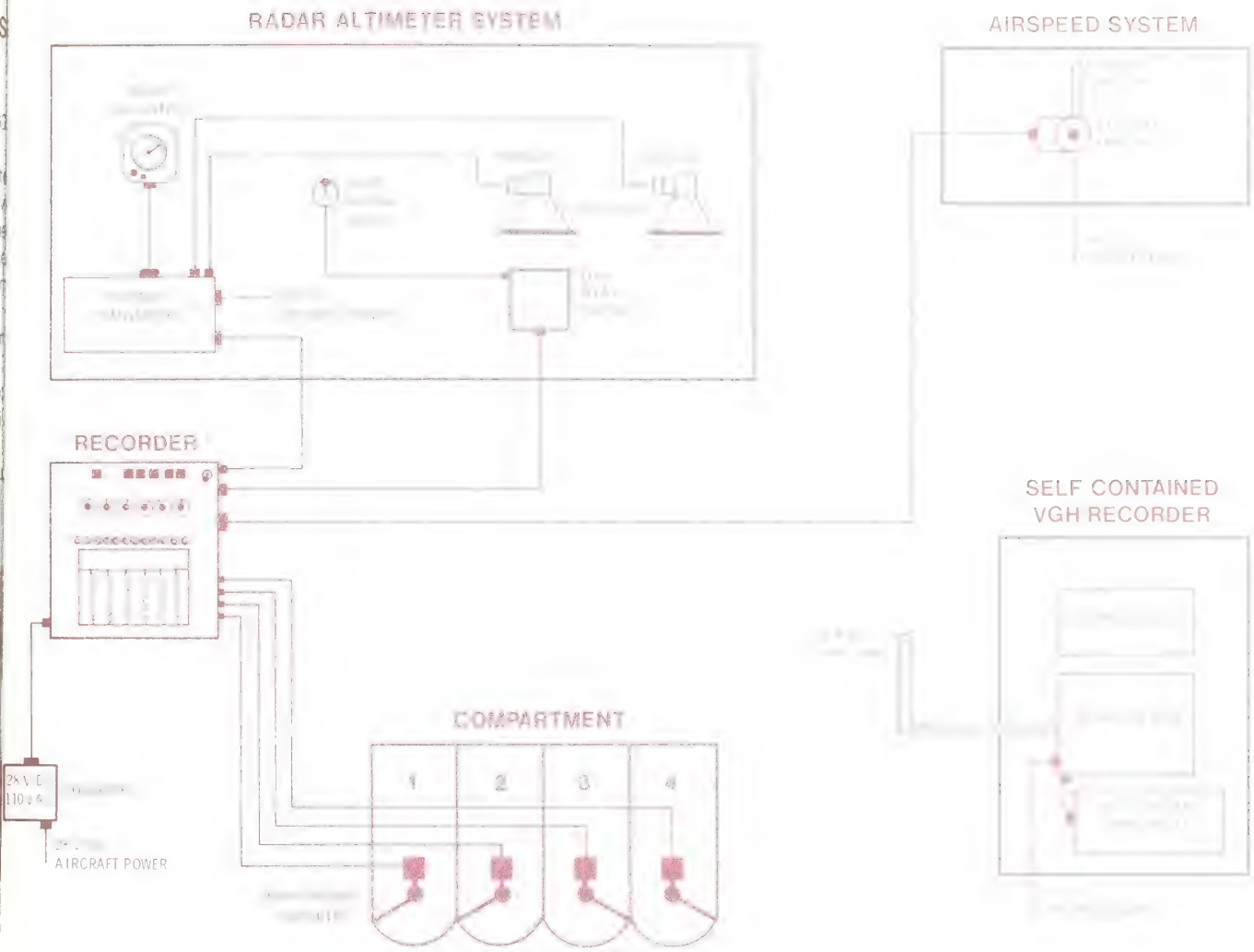

Figure 2.—Schematic of onboard instrumentation.

Drop Configuration and Release Sequence

The release of retardant was correlated to the drop height recording by utilizing the electrical circuit from the door-opening system. The signals at the door-opening solenoids for the four doors were recorded on the six-channel strip chart recorder. The release switch, activated by the pilot, was not used because a slight delay was found between the switch activation and activation of the solenoid and door opening. Recording signals from the door solenoids allowed the monitoring of door-opening when the automatic intervalometer system for sequential or trail drop releases was used, and provided the delay time between releases.

Indicated Airspeed

A pressure transducer was used to measure the aircraft indicated airspeed at the time of the drop (airspeed transducer Bourns Model 538 and Celesco Model CP51DT). The pressure transducer, designed to provide indicated airspeed inputs to an auto pilot, air data computer, or other flight control or monitor system, produces an electrical signal linear with airspeed. Indicated airspeed was monitored by connecting the pressure transducer to the aircraft pitot-static lines.

General Operational Information

A basic VFGH recorder was used to obtain time-history records of aircraft speed, altitude, and normal acceleration during an entire operational mission. From this history, information such as flight duration, time to first drop, dash speed to first drop, rate of descent, maneuver acceleration fraction, drops per flight, time between drops, maximum airspeed, and time from last drop to touchdown can be determined. This information was used to help define the overall mission envelope, as well as interpret recorded data.

The recorder was a basic NASA (National Aeronautics and Space Administration) VGH recorder (Model 47) that contains two pressure-sensitive elements for measuring airspeed and altitude, a galvanometer element for measuring the output of an acceleration transmitter, and a timing mechanism. Data are recorded on photographic paper supplied on removable recording drums. The VGH recorder, being a self-contained system, operated indep

ently from the other on-board measuring systems that have previously been discussed.

A flight log and fire record were kept on each fire mission for which on-board recordings were taken. The information was requested from the airtanker pilot, AIRCO (Air Attack Coordinating Officer), and/or lead plane pilot, and, in addition to normal records (date, time, fire, response area, etc.), provided a description of the fuel characteristics (type, canopy height, etc.), estimated drop height and speed, drop configuration, retardant type, and sketch of the fire perimeter, terrain features, etc., showing approach, tactics, etc. When time and circumstances allowed, the information (especially fuel canopy height) was verified by personnel on the ground.

RESULTS

The study was initiated with the calibration (static test and in-flight) of on-board instrumentation and a thorough review of the program with the air attack personnel involved in the study. During the 1979 fire season, on-board data were collected during 52 operational fire missions. Although minor problems occurred, the primary data-gathering system worked well.

Release Configurations

Data for all drops were tabulated and summarized in appendix table 2. The records of drop conditions provided by the airtanker pilot and air attack personnel were compared with recorded data, and any omissions or differences reconciled. A breakdown of the 52 missions flown, by type of drop or release configuration, is given in the following tabulation.

Release configuration	Missions Number	Missions Percent
Salvo - 4-door 4 compartments, 800 gal (3 028 liters)	2	4
Salvo - 2-door 2 compartments, 400 gal (1 514 liters)	2	4
Trail drop 1 × 2,[1] 400 gal (1 514 liters)	3	6
Trail drop 1 × 4, 800 gal (3 028 liters)	21	40
Trail drop 2 × 2, 800 gal (3 028 liters)	24	46

[1] A trail drop noted as 1 × 2 refers to the number of compartments released times the number of releases.

The data indicate very few four-compartment, 800-gallc (3 028-liter) salvo drops were made with the S2F. Althougl use in an area of considerably heavier fuel might increase the percentage of 800-gallon salvos, it appears that a much greater number of releases of lesser volumes, main ly in the trail or sequential release mode, are the general practice. This is probably significant in view of the genera feeling that a majority of the drops made with the S2F are salvos, due to its relatively small total capacity. One possible reason for the low percentage of salvo drops may have been the large accelerations experienced from pitch up when the released retardant blanks the upload on the S2F's horizontal stabilizer and, hence, a recommendation against high-speed salvo drops (Watts and others 1978). Use of a very short delay time and sequential or trail drop to circumvent pitch-up would be shown by recorded time-delay data.

When the performance of the S2F is considered, using the airtanker performance guides together with the fuels in which the majority of the missions were flown, the types of releases being made are as would be expected. From a tactical standpoint, however, it is surprising that the load is split (more than one pass and release) on only 10 percent of the missions, since multiple drops are often used to pinch off or "x" the front of a spreading fire. Perhaps more than one airtanker is being used to obtain this result, or ground attack personnel are used to the extent that this tactic is only infrequently used.

Analysis of recorded delay times for trail or sequential drops indicated no significant difference between door-opening delays for different drop configurations (1 × 4, 1 × 2, 2 × 2). Furthermore, delay times revealed no trends in either drop speed or drop height. In a few specific instances, however, a very fast trail may have been used to accomplish a slightly delayed 800-gallon salvo (reduced flow rate).

The distribution of delay intervals for all sequential or trail releases (fig. 3) indicates that a delay time between releases of 0.3 and 0.5 seconds was used for 71 percent of all drops. The average delay for all drops was 0.395 seconds, and the median was 0.402 seconds. Delay times were definitely reduced when more than one sequential drop was made, the average delay for the first, second, anc third delay being 0.401, 0.394, and 0.384, respectively. Inspection and analysis of the door-opening histories, in addition to the increasing door-opening speed, also indicate the door-opening intervalometer was seldom, if at all, used. The pilot favored manual activation of the release button (confirmed by the pilot). Although the delays in trail releases were fairly consistent, they were not repetitive. It is possible that manual release was utilized so delay time could be adjusted to compensate for aircraft speed, topography, fuel, fire conditions, or other factors. Flight tests have also demonstrated that delay time is critical for minimizing aircraft pitch-up after release. Use of the manual release rather than the automatic intervalometer system also results from lack of definite settings on the switch (a variable-speed potentiometer is used providing continuous "slow" to "fast" settings), possibly leading to a lack of pilot confidence in the system. (Nearly all CDF S2F's have identical intervalometer systems.)

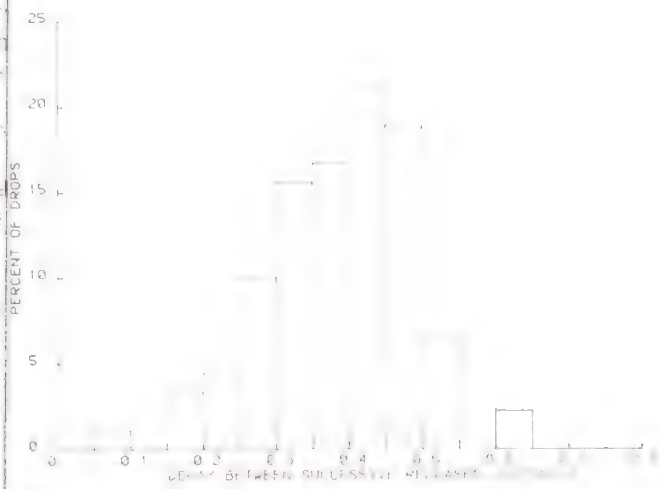

Figure 3.—Delay times for sequential or trail drops.

Figure 4.—Drop height above the fuel at initial door opening.

Drop Height

The drop height (above the fuel or canopy), determined from recordings from the pulse radar altimeter system for each drop, was analyzed. The height at initiation of door opening for each compartment was determined. (The initiation of door opening for each door was recorded on the same time-base strip chart as the drop height.) Thus, for a single-door trail drop (1 × 4), the height at the time of each of the four door openings was determined. The minimum drop height occurring during the pass, as well as the time it happened in relation to the initial release, was also noted. Specifics for each drop can be found in table 2 (see appendix).

The distribution of drops by drop height above the fuel at the time the first door is opened is shown in figure 4. The lowest height at the initiation of release was 63 ft, and the highest 564 ft. The average height for all releases at drop initiation was 160 ft; the median was 144 ft. Because visual examination of the traces indicated that the drop height tended to decrease following the initial release, with the absolute minimum usually occurring after the last release, a similar analysis of drop heights at successive releases made during the same pass (sequential or trail drop) was conducted. The analysis showed the average heights at the point of the second, third, and fourth release were 150, 118, and 109 ft, respectively; the corresponding median heights were 127, 114, and 112 ft. The median for consecutive releases following the initial release was determined from a smaller sample, however, with 40 percent of the drops being 1 × 4 and 50 percent being 2 × 2 trail drops. A definite trend of decreasing drop height following release can be concluded. (All average and median drop heights are shown in table 1.) Assuming that uphill drops (considered a poor practice or prohibited for safety reasons) were not being made, the lowest drop height for a pass usually occurs significantly

Table 1.—Comparison of average and median drop heights for all releases

Drop sequence	Number in sample	Drop height	
		Average	Median
		Feet	
1 (initial)	[illegible]	160	144
2	52	150	127
3	21	118	114
4	21	109	112
	n = 146	$\overline{DH}$ = 143	DH[illegible] = 123

after initial release. To further define the minimum absolute drop height, its occurrence in relation to the initial release was determined from the strip-charts and recorded. Using these observations, the frequency of minimum heights for all missions or passes and the time of occurrence with reference to the initial release was determined and is shown in figures 5 and 6.

Although the point of release provides a definite point from which height can be measured, it does not always coincide with the height or trajectory of the retardant. (The drop height and the initial height are similar when the flight path and ground are relatively level, or when the flight parallels the slope of the land.) Thus, drop height (especially minimum drop height) must be monitored from initial release until the retardant is evacuated from the tank.

Flow rate tests of the "Aero-Union-tanked" type S2F (similar to the tanker used in this study) previously conducted had door-opening times of 0.26 to 0.32 seconds for any door-opening combination, and retardant evacuation

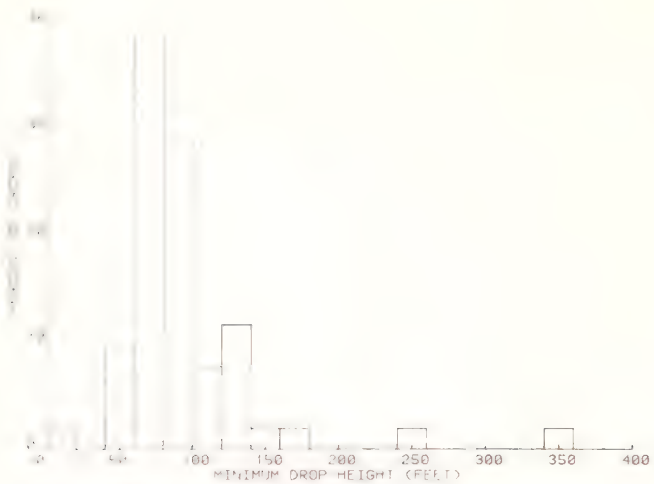

Figure 5.—Minimum drop heights.

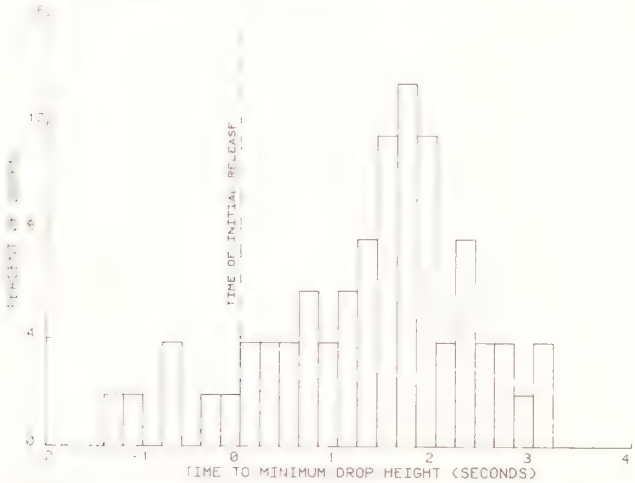

Figure 6.—Variation in time from initial release to minimum height.

times of 0.50 seconds (Swanson and others 1976). The door-opening times were found to be faster than the acceleration of the fluid and multiple door opening did not alter the door-opening rates. Thus, evacuation time was constant for all drops. Hence, the 0.50-second constant evacuation time added to any delays occurring for other than salvo drops defined the period of interest for which drop height changes may have occurred. Figures 7 and 8 show the frequency of time required for all retardant to be evacuated from the tank or tanks and the time from evacuation (time 0) to the minimum drop height. (Negative values indicate the minimum drop height occurred prior to the evacuation of the retardant.) Because the minimum drop height occurred before the tanks were evacuated in 40 percent of the drops and after evacuation in 60 percent of the drops, and because the large majority of the drops were in a trail or sequential configuration, it appears the drop height at the point of initial release would be most representative of the drop height influencing retardant breakup and dispersion. Drop height during the time from or before initial release to evacuation can be measured using recordings from the radar altimeter; however, a visual examination of the recording is normally sufficient to determine whether significant changes in drop height have occurred during actual retardant release.

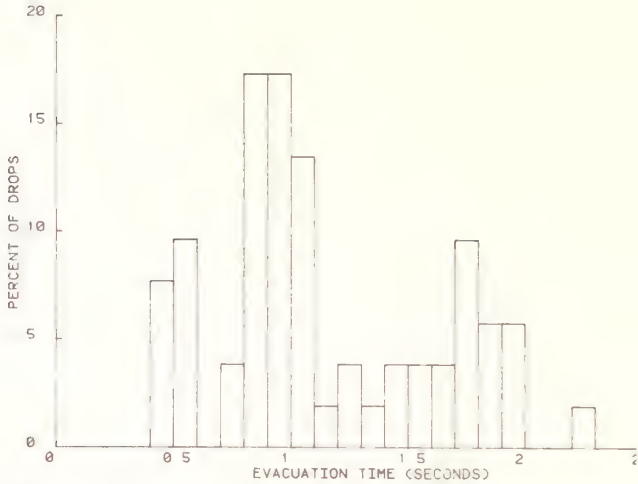

Figure 7.—Evacuation time for all drops.

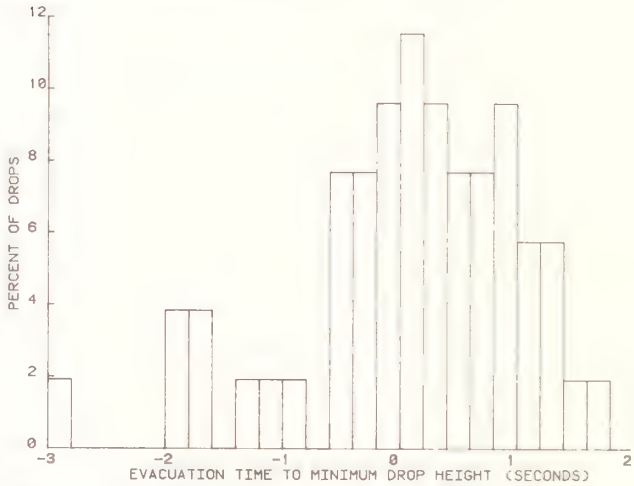

Figure 8.—Variation in time from tank evacuation to minimum height.

The average minimum height for all missions was 94 ft (28.7 m), and the median 86 ft (26.2 m). The minimum height was less than the height at the time of initial release during 98 percent of the missions (160 ft [48.9 m] average height at release compared to 94 ft [28.7 m] average minimum drop height).

Indicated Airspeed/VGH Recordings

Due to problems in obtaining, installing, calibrating, and maintaining the airspeed monitoring instrumentation (including VGH recorder), no VGH airspeed data were obtained during the 52 missions. By monitoring the airspeed transducer, however, the indicated airspeeds during 13 missions and during 34 releases were obtained. Although limited data were obtained with the instrumentation, the methods of data collection and the data proved to be adequate.

The average indicated airspeed for those drops monitored was 119 knots (61.2 m/s); the median was 124 knots (63.8 m/s). The frequency of indicated airspeed for all drops is shown in figure 9, drops ranging from 97 to 135 knots (49.9–69.4 m/s). The drop speed at door opening

r trail or sequential drops tended to increase for c
ive releases. The average airspeed being 116, 118, 122,
d 125 knots (59.7, 60.7, 62.8, and 64.3 m/s) for the four re-
ases of a 1 × 4 sequence (the medians for the four
leases showed corresponding airspeeds of 121, 125,
7, and 129 knots [62.2, 64.3, 65.3, and 66.4 m
ely), this trend would normally be expected beca
ost drops are made downhill (decreasing drop heights
ring the drop were confirmed), and under such condi-
ns, airspeed is less controllable.

gure 9.—Indicated airspeeds at time of
lease.

Although VGH recordings were not obtained for the 52
ie operation and usefulness of such
data have been previously demonstrated. General opera-
nation has be
by J. Jewel, NASA, using recorders on DC6, DC7, C119,
and S2F airtankers during 1972-74 fire seasons.[1] Data
collected during approximately 513 flight hours and for
1 658 drops (722 missions) for the four aircraft were
reported. Data included flight duration histories, times to
drop, drop speeds, and rates of descent. Examples of such
data collected for a CDF-Hemet Valley Flying Service S2F
during September to November 1974 are shown in figure
10. These data, although collected for the same type of air-
craft and for missions flying from the same air attack
base, may only be generally related to the data and find-
ings resulting from this study. The histories (times) for
particular missions are likely similar; however, drop con-
figurations were different. Salvo drops predominated dur-
ing the 1974 study; in this study, the majority were trail or
sequential drops.

VGH recordings can provide information that can be
useful when defining drop conditions and flight
envelopes and when interpreting and verifying
associated in-flight monitoring systems.

[1] A, Report to the National Airtanker Screen
12 and 13, 1975, Reno, NV

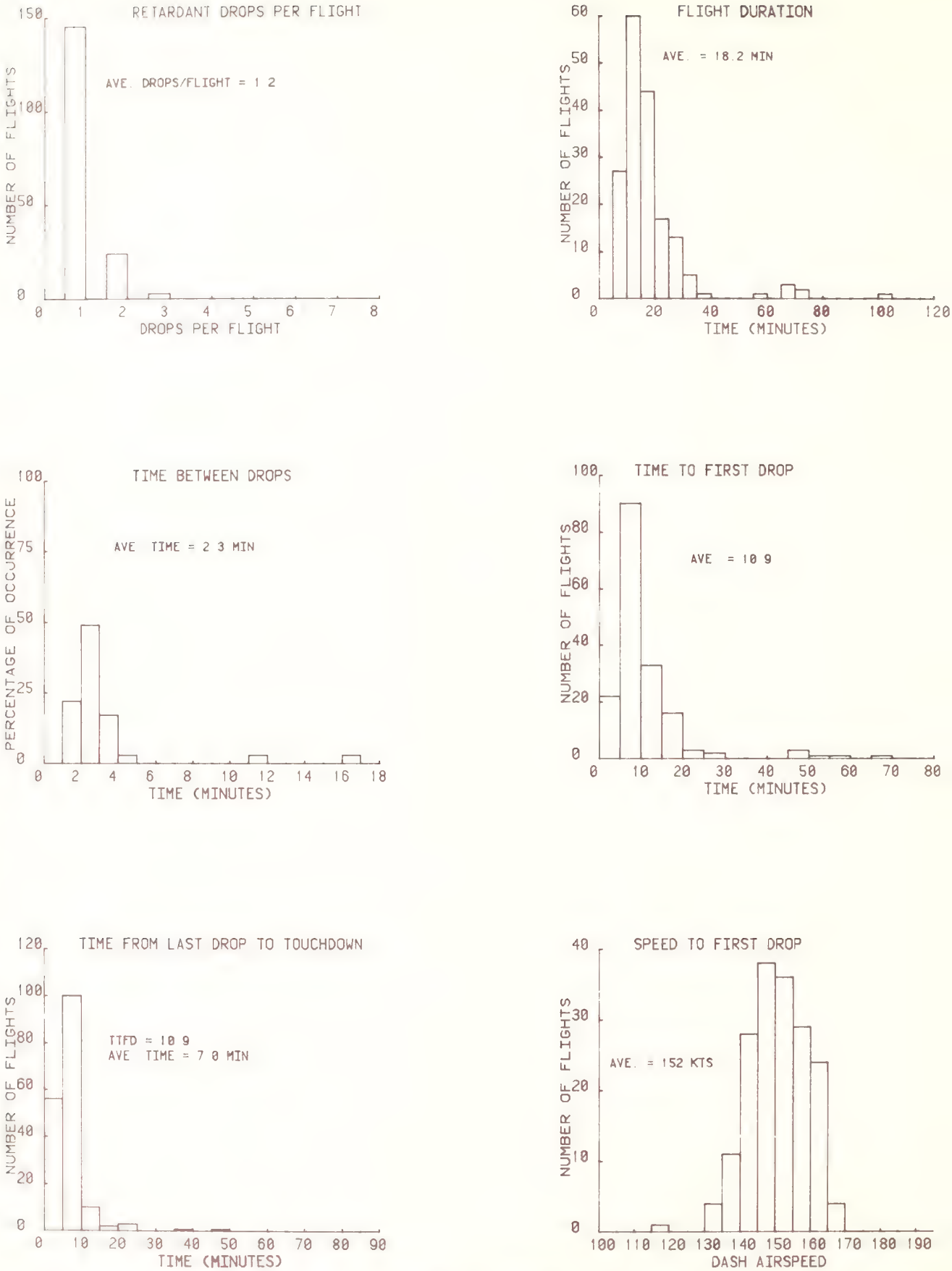

Figure 10.—Examples of data summarized from VGH recordings in a CDF-Hemet Valley Flying Service S2F airtanker (from J. Jewel, NASA, 1975).

CONCLUSIONS

Data concerning operational aerial retardant use were gathered on actual retardant-dropping missions and analyzed. The data and subsequent analysis confirm that the procedures for evaluating airtanker performance and retardant distribution including instrumentation on simulated drops are sound and adequate.

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Table 2.—Summary of on-board data collected during the study

DATE	FIRE ID	DROP	DROP HEIGHT (FT.) 2/				AIRSPEED (KNOTS) 2/				DELAY (SEC) 3/				MIN	TIME TO 4/ FIRST FIRE
	NAME	No. 1/	1	2	3	4	1	2	3	4	1	2	3	4	(PERIMETER) FT	MIN (TIME TO FIRE)
6/09/79	PLATS 1	1195	12X2	90	74	0	0	0	0	0	0.49	0.00	0.00	0	64	1.14
6/09/79	PLATS 2	1195	1X4	123	119	119	124	0	0	0	0.35	0.34	0.30	0	[illegible]	1.[illegible]
6/09/79	PLATS 3	1195	2X2	74	53	0	0	0	0	0	0.55	0.00	0.00	0	63	1.10
6/09/79	PLATS 4	1195	2X2	99	69	0	0	0	0	0	0.59	0.00	0.00	0	60	0.[illegible]
6/09/79	PLATS 5	1195	1X4	150	149	128	111	0	0	0	0	0.52	0.36	0.31	13	2.[illegible]
6/09/79	PLATS 6	1195	1X4	126	119	113	100	0	0	0	0	0.39	0.39	0.4[illegible]	[illegible]	2.[illegible]
6/10/79	KIEN	1296	2X2	153	155	0	0	0	0	0	0	0.59	0.00	0.00	78	1.[illegible]
6/15/79	RC ASSIST	12-759	1X2	261	181	0	0	0	0	0	0	0.60	0.00	0.00	96	2.0[illegible]
6/18/79	JOSHUA 1	1252	1X4	111	99	88	84	0	0	0	0	0.48	0.50	0.46	35	1.44
6/18/79	JOSHUA 2	1252	1X4	174	171	144	125	0	0	0	0	0.34	0.47	0.40	95	2.44
6/18/79	JOSHUA 3	1252	1X4	76	85	110	123	0	0	0	0	0.5[illegible]	0.47	0.47	54	0.[illegible]
6/18/79	RAWSON 1	1256	1X2	63	81	0	0	0	0	0	0	0.52	0.00	0.00	63	0.00
6/18/79	RAWSON 2	1256	1X2	174	169	0	0	0	0	0	0	0.41	0.00	0.00	95	[illegible]
6/18/79	RAWSON 3	1256	2X2	111	146	0	0	0	0	0	0	0.55	0.00	0.00	87	0.33
6/18/79	RAWSON 4	1256	1X4	99	88	73	61	0	0	0	0	0.26	0.28	0.28	41	1.50
6/18/79	RAWSON 5	1256	1X4	175	161	138	113	0	0	0	0	0.48	0.40	0.37	[illegible]	1.04
6/18/79	RAWSON 6	1256	1X4	98	101	103	108	0	0	0	0	0.2[illegible]	0.26	0.26	76	0.87
6/18/79	RAWSON 7	1256	1X4	186	175	174	143	0	0	0	0	0.48	0.41	0.42	85	1.[illegible]
6/18/79	RAWSON 8	1256	1X4	163	164	149	136	0	0	0	0	0.45	0.43	0.36	130	1.[illegible]
6/19/79	JOSHUA 4	1252	1X4	101	103	95	88	0	0	0	0	0.35	0.30	0.36	89	1.48
6/24/79	BURFO	12-986	1X2	328	365	0	0	0	0	0	0	0.34	0.00	0.00	136	2.40
6/25/79	HALL 1	1297	1X2	159	106	0	0	0	0	0	0	0.35	0.00	0.00	98	0.[illegible]
6/25/79	HALL 2	1297	12X2	151	124	0	0	0	0	0	0	0.44	0.00	0.00	61	1.35
6/25/79	HALL 3	1297	2X2	68	76	0	0	0	0	0	0	0.43	0.00	0.00	51	1.14
6/27/79	CREEK	1310	12X2	89	111	0	0	0	0	0	0	0.38	0.00	0.00	75	0.76
6/29/79	CABAZON 1	12-1086	2X2	298	285	0	0	0	0	0	0	0.10	0.00	0.00	138	0.56
6/29/79	CABAZON 2	12-1086	2X2	125	126	0	0	0	0	0	0	0.33	0.00	0.00	124	0.70
6/29/79	CABAZON 3	12-1086	2X2	266	248	0	0	131	131	0	0	0.46	0.00	0.00	133	1.70
6/29/79	CABAZON 4	12-1086	2X1	184	0	0	0	102	0	0	0	0.00	0.00	0.00	155	1.[illegible]
6/29/79	CABAZON 5	12-1086	2X2	564	513	0	0	0	0	0	0	0.15	0.00	0.00	356	3.1[illegible]
6/29/79	CABAZON 6	12-1086	1X4	239	215	200	176	110	105	105	110	0.28	0.24	0.24	90	1.7[illegible]
6/29/79	CABAZON 7	12-1086	2X2	256	274	0	0	99	97	0	0	0.32	0.00	0.00	249	0.1[illegible]
6/30/79	WASSON 1	1337	1X4	130	124	115	111	113	113	114	121	0.33	0.36	0.39	100	1.24
6/30/79	WASSON 2	1337	1X4	136	128	118	125	125	124	128	12[illegible]	0.34	0.49	0.49	110	1.96
6/30/79	WASSON 3	1337	1X4	73	89	95	106	126	129	135	165	0.44	0.44	0.43	63	1.03
6/30/79	WASSON 4	1337	1X4	113	113	108	121	121	125	125	131	0.42	0.49	0.35	76	1.03
6/30/79	WASSON 5	1337	12X2	213	173	0	0	123	125	0	0	0.40	0.00	0.00	89	1.57
9/02/79	MORUNGO	61-1354	12X2	263	223	0	0	108	103	0	0	0.56	0.00	0.00	161	2.00
9/03/79	OLIVE 1	1365	12X2	63	60	0	0	121	127	0	0	0.48	0.00	0.00	51	0.54
9/03/79	OLIVE 2	1365	12X2	245	239	0	0	114	114	0	0	0.53	0.00	0.00	156	2.27
9/03/79	OLIVE 3	1365	4X1	140	0	0	0	114	0	0	0	0.00	0.00	0.00	93	1.4
9/07/79	YNEZ	1398	1X4	114	91	70	64	0	0	0	0	0.58	0.57	0.62	64	1.80
9/11/79	HIGHLAND	938	12X2	124	106	0	0	0	0	0	0	0.51	0.00	0.00	88	1.80
9/12/79	SAN FELIPE 1	947	12X2	161	138	0	0	0	0	0	0	0.24	0.00	0.00	93	1.32
9/12/79	SAN FELIPE 2	947	12X2	183	165	0	0	0	0	0	0	0.44	0.00	0.00	100	1.84
9/13/79	CANYON 1	1456	1X4	200	188	175	165	0	0	0	0	0.20	0.18	0.18	113	2.21
9/13/79	CANYON 2	1456	1X4	99	73	51	30	0	0	0	0	0.46	0.43	0.40	15	1.50
9/13/79	CANYON 3	1456	2X2	131	86	0	0	0	0	0	0	0.48	0.00	0.00	63	0.80
9/13/79	ORTEGA	1454	12X2	176	153	0	0	0	0	0	0	0.38	0.00	0.00	89	1.56
??	SAN DIA 1	??	4X1	124	0	0	0	0	0	0	0	0.00	0.00	0.00	63	0.68
??	SAN DIA 2	??	1X4	189	150	113	88	0	0	0	0	0.42	0.36	0.44	79	1.79
??	SAN DIA 3	??	2X1	83	0	0	0	0	0	0	0	0.00	0.00	0.00	56	0.30

1/ Order Number, CDF or FS Fire Number.
2/ Columns 1-4 refer to release numbers.
3/ [illegible]
4/ [illegible]

George, C. W. Measurements of airtanker drop conditions during firefighting operations. Res. Pap. INT-299. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 10 p.

Operational parameters for an S2F airtanker were monitored on a series of wildland fires to verify previous assumptions concerning typical flight envelopes. Results confirmed the validity of the procedure and instrumentation used in obtaining real-time aircraft drop height, speed, drop configuration, release sequence, and other related data. In-flight measurements support general assumptions made during previous studies dealing with delivery systems, retardant properties, and in the development of guidelines derived therefrom.

KEYWORDS: airtanker, tank and gating system, firefighting mission, operational use, envelope, drop conditions, drop height, aircraft speed, drop configuration, release sequence, fire retardant, ground distribution pattern, safety

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January 1983

Lifting, Storage, Planting Practices Influence Growth of Conifer Seedlings in the Northern Rockies

Stephen E. McDonald
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RESEARCH SUMMARY

In two studies in northern Idaho, Engelmann spruce, lodgepole pine, and western larch nursery stock were lifted and stored under a variety of regimes and planted throughout the spring planting season. Lifting-storage regimes included: (1) fall lifting and storage at 28° F (-3° C) until planted; (2) spring lifting and storage at 34° to 38° F (10° to 3° C) until planted; (3) spring lifting and snow cache storage; and (4) spring lifting just prior to planting. Planting date had the strongest influence on survival and growth with early plantings performing better than late plantings. Stock lifted in the fall and stored at subfreezing temperatures survived and grew as well or better than stock conventionally lifted and stored, especially when planted late in the season. Larch benefited most from fall lifting and overwinter storage at subfreezing temperatures, followed by spruce and lodgepole pine. Some fall lifting and overwinter storage at 28° F is now a standard procedure at the Coeur d'Alene Nursery.

Cover Photo: The Coeur d'Alene Nursery, Coeur d'Alene, Idaho, as it appeared when newly completed in 1963. This USDA Forest Service Nursery is administratively attached to the Idaho Panhandle National Forests and provides forest tree planting stock to the National Forests of the Northern Rocky Mountains. The Nursery has cooperated with the Intermountain Experiment Station in many studies to improve nursery and reforestation methods.

United States
Department of
Agriculture

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Lifting, Storage, Planting Practices Influence Growth of Conifer Seedlings in the Northern Rockies

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INTRODUCTION

Until 1976, the Coeur d'Alene Nursery, like most northern temperate zone nurseries, lifted all of its coniferous bare root stock in the early spring for later spring planting. Typically stock has been lifted in March, placed in cold storage (34° to 38° F [1° to 3° C]), and planted when conditions were favorable at the planting site. With the large geographical and elevational range served by the nursery, the planting season can extend into early July. Although every effort has been made to lift stock while it was still dormant and to plant as early as possible, weather conditions and the magnitude of the lifting, sorting, and packing job often resulted in undesirable delays.

Investigations in Canada, the northeastern United States, and Europe have shown that trees can be lifted in the fall and stored overwinter (Hocking and Nyland 1971). This is feasible when storage temperatures are lowered to below freezing to reduce physiological activity and pathogen growth (Nyland 1974a), and if the trees are protected from desiccation by a suitable vapor barrier (Nyland 1974b). The potential advantages of fall lifting and frozen storage of nursery stock prompted study of the technique at the Coeur d'Alene Nursery in 1972.

This paper reports the results of nursery trials in 1972 and a limited field trial in 1973.

The study was conducted to obtain comparative information on the effects of storage conditions, in combination with various spring planting dates, on the survival of outplanted stock. The primary objective was the testing of overwinter storage at subfreezing temperatures. Other temperature regimes were used as controls or as additional alternatives to conventional storage methods. Because planting normally extends over a period of 2½ to 3 months in the Northern Rocky Mountain area, planting date was also studied as an interactive variable.

PHASE I. NURSERY-BASED SURVIVAL COMPARISONS, 1972

Methods

Three coniferous species, Engelmann spruce (*Pi[illegible] mannii* Parry), lodgepole pine ([illegible] *rayana* [Grev. and Balf.] Engelm.) and wester[illegible] *occidentalis* Nutt.) were selected for trial. Lodgepole pin[illegible] spruce were used because of the long storage periods [illegible] involved; larch because of past storage diffic[illegible]

The objective of this initial study was to [illegible] with various spring [illegible] stock. Storage regimes were as follows:

1. **Frozen**.—On November 17, 1971, 1,125 trees of [illegible] cies were lifted and sealed in plastic (4-mil polyethy[illegible] put into [illegible] 38° F (3° C) for 2 days [illegible] finally at 28° F [illegible] storage period. [illegible] with three bundles [illegible] following spring the [illegible] in refrigerated storage at 34° to 36° F (1° to 2° C) to thaw. By [illegible] age temperature was subfreezing. Tree tissue [illegible] not determined.

2. **Refrigerated**.—On March 18, 1972, 1,125 trees of [illegible] cies were lifted and placed in refrigerated stora[illegible] were packaged in polyethylene-lined Kraft bags. This [illegible] moss was placed around the seedlings' roots.

3. **Snow cached.**—On March 18, 1972, 1,125 trees of each species were lifted, packaged, and stored as described in 2 above. Five days later these seedlings were placed in a snow cache near Coeur d'Alene at an elevation of 4,800 ft (1 463 m). The cache was constructed according to methods described by Dahlgren and others (1974). At each subsequent planting date the cache was opened, stock removed, and the cache resealed. The cache was still usable in late July, long after the last stock had been removed.

4. **Fresh.**—Seedlings were freshly lifted just prior to each planting, refrigerated at 34° to 36° F (1° to 2° C) overnight, and planted the next day.

Stock survival after planting was tested using the Variable-Moisture-Stress-Plot Technique described by Boyd and others (1972). Trees were planted on five dates: April 4, April 25, May 16, June 6, and June 27, 1972 (table 1). On each date, three 25-tree bundles of each species from each storage treatment were planted in each of three moisture stress plots, as follows:

Table 1.—Length of nursery stock storage prior to planting, 1971-72

Planting date	Length of storage		
	Snow cached	Refrigerated	Frozen
	Days		
April 4	13	18	139
April 25	34	39	159
May 16	55	60	180
June 6	76	81	201
June 27	97	102	222

1. **Low stress.**—Soil moisture was maintained above 30 percent of field capacity by irrigation and periodic removal of weed competition.

2. **Moderate stress.**—Soil moisture was allowed to deplete to natural levels. Weed competition was periodically removed. Plots were not irrigated.

3. **Extreme stress.**—Soil moisture was allowed to deplete to natural levels. Weed competition was undisturbed. Plots were not irrigated.

Seedlings were planted 12 inches (30.48 cm) apart, within plowed furrows 18 inches (45.72 cm) apart. Transplanting boards were used to facilitate planting. Soil moisture in the plots was monitored during the summer to aid in timing of irrigation and weeding.

Until all five plantings were completed, soil moisture in all the stress plots was kept at or above 50 percent availability by a temporary watering system. After July 1, the moderate and extreme stress plots were not watered. Low and moderate stress plots were weeded every 4 weeks. The low stress plot was irrigated five times and each watering lasted an average of 6 hours. An average of 0.96 inches (2.45 cm) of water was applied at each watering. Distribution of rainfall during the planting and stress period is shown in figure 1.

Survival tallies were made on August 1, September 2, and October 5, 1972. Analysis of variance for a factorial design was applied to the October 5 data of each species with tests for survival differences attributable to storage, planting date, stress level, and possible interactions among these main variables. Survival percentages were transformed to the arc sin $\sqrt{\text{percent}}$ for analysis.

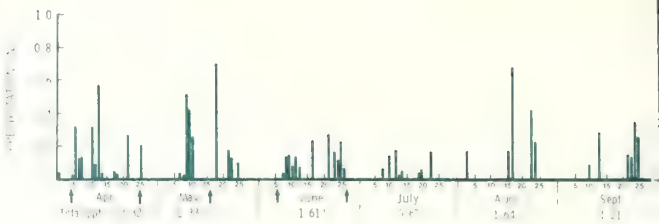

Figure 1.—Growing season precipitation, 1972, Coeur d'Alene, Idaho.

Results

ENGELMANN SPRUCE

Figure 2 depicts the survival of spruce under all of the test conditions. With increasing stress, the average survival declined from 90 percent under low stress to 54 percent at moderate stress and finally to 39 percent under the severe moisture stress regime, indicating a good range of test conditions. Differences were highly significant (table 2).

Under low stress conditions (fig. 2a) stock storage regimes had no significant influence on survival for the first four planting dates. However, survival of the stock planted on June 27 was greatly influenced by storage treatment. Survival of spring-lifted stock stored in both snow cache and regular nursery storage was much lower for the June 27 planting.

Moderate stress (fig. 2b) produced a similar but less uniform pattern with significant survival differences attributable to storage evident in both the fourth and the fifth plantings. This pattern indicates that stock deterioration in storage and greater planting site stresses reduced survival.

Under extreme moisture stress (fig. 2c), the survival of spruce stock became quite erratic, but the trends established under low and moderate stress were still evident. Much of the variation in survival at the extreme stress level may have been caused by the inability to create a uniformly severe soil moisture stress due to chance soil moisture and weed competition variations.

Of particular interest was the performance of freshly lifted and planted spruce stock. Lifting and planting during late May and early June caused significantly lower survival rates than either earlier plantings or the final planting of June 27. This period of poor survival coincides with the period of rapid shoot elongation in the nursery. By June 27 elongation had probably slowed considerably and succulent new tissue had probably started to harden. Unfortunately, no data are available to test this hypothesis.

In mid-July some outstanding differences in spruce bud bursting and subsequent growth were noticed and data on bud and shoot abnormalities were gathered. For each treatment unit a count was made of abnormal terminal shoots and/or buds, and expressed as a percentage of the unit population. Since the buds of the trees from the last planting (June 27) were just beginning to break, they were not considered in this examination. Stock lifted in the spring and planted shortly afterward had by far the greatest number of abnormal terminal buds and shoots (27 percent) (table 3). Seedlings lifted in the spring and stored in refrigerators or a snow cache were intermediate in frequency of abnormal terminals (8 to 10 percent). The least abnormality occurred in seedlings lifted in November and held at 28° F (-2° C) until planted (2+ percent).

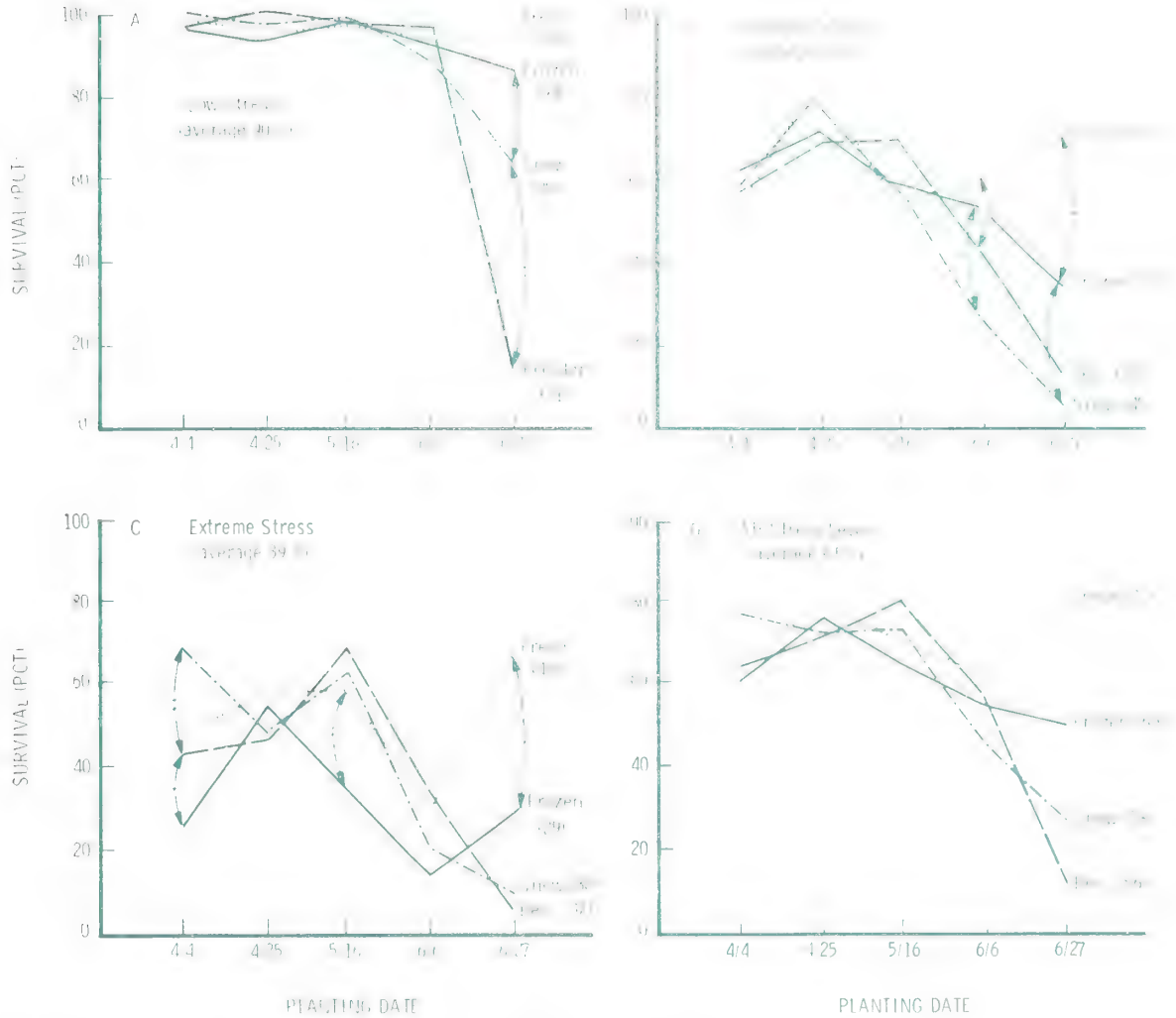

Figure 2.—First-season survival of Engelmann spruce planting stock under four storage regimes, planted throughout the spring season. Figures in parentheses are average survivals over all planting dates. Significance differences attributable to storage are shown by * and ** (p = 0.05 and 0.01, respectively) and connecting arrows.

Table 2.—Analysis of variance table, Engelmann spruce, 1972 study

Source	DF	MS	F	Prob. < F
Blocks	2	0.4222	8.3470**	0.0007
Storage	3	.2528	4.9969**	.0031
Date	4	1.0478	20.7144**	.0001
Stress	2	7.9724	157.6035**	.0001
Storage X date	12	.2704	5.3453**	0001
Storage X stress	6	.0772	11.5252	.1750
Date X stress	8	0887	1.7544	.0926
Storage X date X stress	24	.0300	.5925	9308
Error	118	.0506		

**Significant at the 99 percent level of confidence

Table 3.—Abnormal terminal buds on Engelmann spruce by storage and planting date, 1971-72

Planting date	Stock storage treatment			
	Snow	Regular	Fresh	Frozen
	Percent			
April 4	9.3	12 4	14 6	[illegible]
April 25	4.0	8.0	27 5	[illegible]
May 16	22.2	5 3	32 4	[illegible]
June 6	5.3	6 6	28 4	1 3
Average	10.2	8.1	26 7	2 3

LODGEPOLE PINE

The soil moisture stress levels applied in the test had no influence on lodgepole pine stock (fig. 3). Survival averaged 90 percent at all three stress levels. Obviously, the test procedures failed to create a sufficient range of moisture stress to adequately test this species. This survival tenacity of lodgepole pine under moisture stress conditions that were so devastating to spruce and larch stock was rather surprising. Previous testing of ponderosa pine, considered the most drought tolerant of species raised at the Coeur d' Alene Nursery, has resulted in very low survival rates at high stress levels (Boyd and others 1972).

Both storage regime and planting date had a highly significant effect on pine survival at all stress levels (table 4). Until the June 27 planting, survival was excellent at all stress levels and storage regimes. Stock stored in regular nursery storage virtually failed when planted in late June. Stock stored in the snow cache survived significantly better, but still compared poorly to frozen and fresh stock.

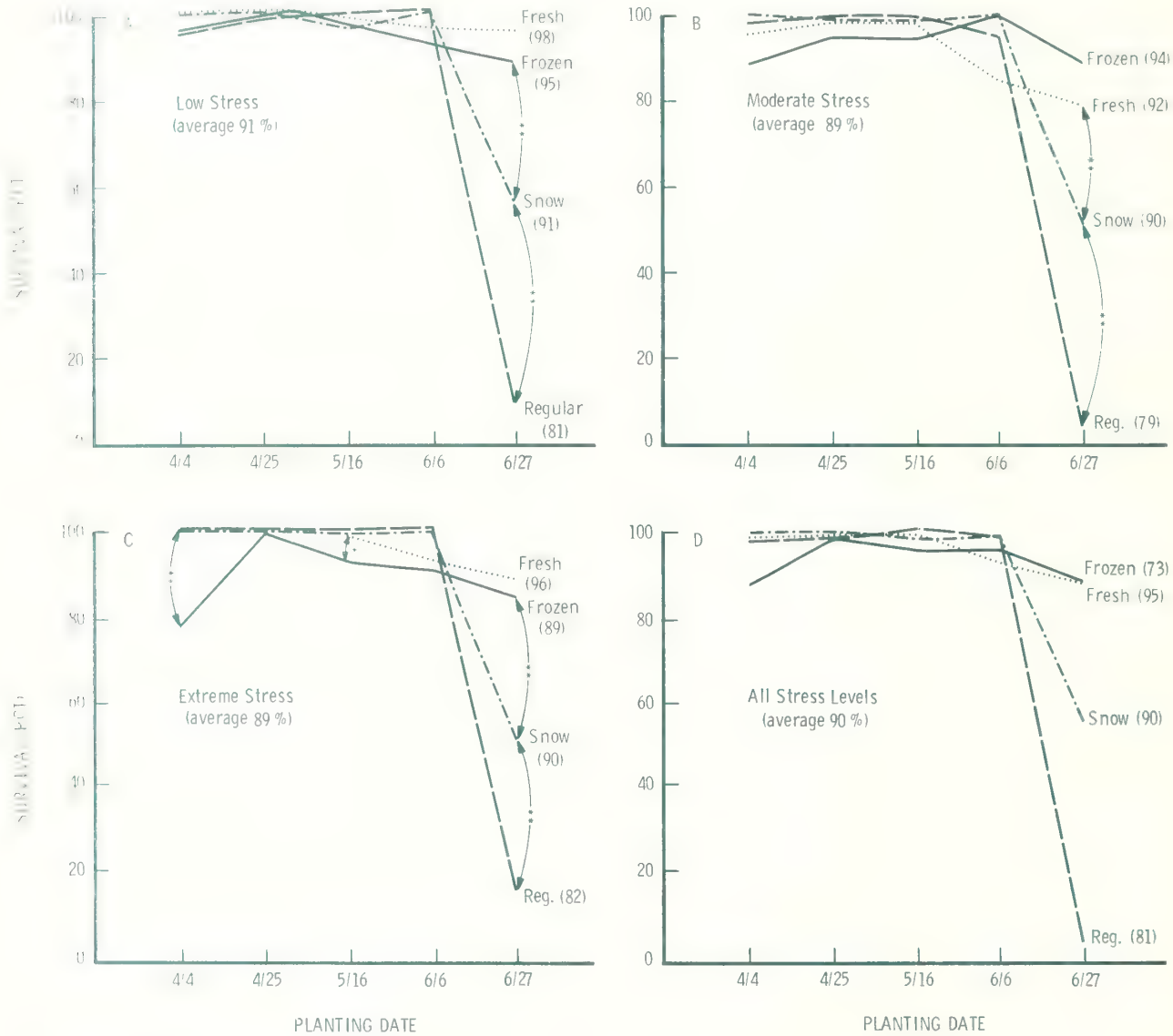

Figure 3.—First-season survival of lodgepole pine planting stock under four storage regimes, planted throughout the spring season. Figures in parentheses are average survivals over all planting dates. Significance differences attributable to storage are shown by * and ** (p = 0.05 and 0.01, respectively) and connecting arrows.

Table 4.—Analysis of variance table, lodgepole pine, 1972 study

Source	DF	MS	F	Prob. < F
Blocks	2	0.0375	2.7535**	0.066
Storage	3	.2190	16.0772**	.0001
Date	4	2.5211	185.0968**	.0001
Stress	2	.0380	2.7920	.0636
Storage X date	12	.5275	38.7251**	.0001
Storage X stress	6	.0509	3.7343**	.0023
Date X stress	8	.0061	.4500	.8886
Storage X date X stress	24	.0169	1.2417	.2214
Error	118	.0136		

**Significant at the 99 percent level of confidence

WESTERN LARCH

All three main variables (storage, stress, and planting date) had highly significant influences on larch survival in the analysis of variance (table 5). Storage-date interaction was also highly significant; stress-date interaction was significant. Increasing stress caused a significant decline in the survival of western larch as it did with Engelmann spruce (fig. 4). At the low stress level (fig. 4a) survival generally declined when trees were planted later than the second planting (April 25) regardless of storage. Frozen stock survived exceptionally well (above 80 percent) even when planted as late as June 27. Survival of freshly lifted stock declined when planted after April 25 and reached a low of 30 percent survival at the fourth (June 6) planting, but regained its potential when lifted and planted on June 27. Snow cache and regularly stored stock survived well when planted through June 6 but failed when held until June 27 for planting.

Moderate stress reduced overall survival and, as with spruce, resulted in an expression of storage deterioration at an earlier planting date than at low stress levels (fig. 4b). Survival under moderate stress declined to unacceptable levels (30 to 50 percent) by the third planting (May 16). Survival increased from the fourth to the fifth planting with freshly lifted stock. Both fresh and frozen stock survived significantly better than regular or snow cache stock from the last planting.

Under extreme stress the same pattern prevailed but at a lower overall survival rate (29 percent) and with less overall variability in survival rates (fig. 4c).

Table 5.—Analysis of variance table, western larch, 1972 study

Source	DF	MS	F	Prob. < F
Blocks	2	0.1956	5.6845**	0.0047
Storage	3	.5000	14.5315**	.0001
Date	4	2.2613	65.7300**	.0001
Stress	2	5.2465	152.5015**	.0001
Storage X date	12	.4905	14.2583**	.0001
Storage X stress	6	.0330	.9588	.5427
Date X stress	8	.0773	2.2484*	.0282
Storage X date X stress	24	.0404	1.1749	.2787
Error	118	.0344		

*Significant at the 95 percent level of confidence
**Significant at the 99 percent level of confidence

Discussion

[illegible] than in areas planted in June. Soil moisture monitoring [illegible] adequate to verify any differences in soil moisture depletion [illegible] to be less from the first planting than from the second planting under moderate and severe stress levels.

If the observed [illegible] planted later, the effect of planting date on survival as reported in our data may be a conservative estimate. This confounding would affect the [illegible] effects.

The performance of the [illegible] the most surprising result of this study. Fresh spruce and [illegible] pole pine stock survived as well as, or better than, all other stock at each planting date and stress level. Fresh larch stock survived poorly compared to stored stocks [illegible] plantings, but had the best average survival rate in the June 27 planting. Whether survival of freshly lifted stock [illegible] ditions imposed in this study has any practical application could only be determined by further study. [illegible] ing" may have limited utility. In this study the maximum time between lifting and planting was 1 day, hardly typical of the usual planting operation. Should longer periods of field storage have a different effect on the various stocks studied, the results of typical operational field plantings with "fresh" stock could be much different from the results of this study.

Lest the temperature of the frozen stock [illegible] cause of its performance, it should be [illegible] at which the frozen stock was lifted may be as important or more important than the storage temperature. Stock for this treatment was lifted in a state of rest or deep dormancy before its chilling requirements had been satisfied (Romberger 1963). The relative importance of temperature and state of dormancy needs more clarification. The low incidence of abnormal terminal buds and shoots in frozen spruce stock suggests that: (1) bud chilling requirements are not being satisfied with normal overwinter nursery field climate, lifting, and storage regimes, or (2) spring lifting and storage procedures upset the normal [illegible] growth.

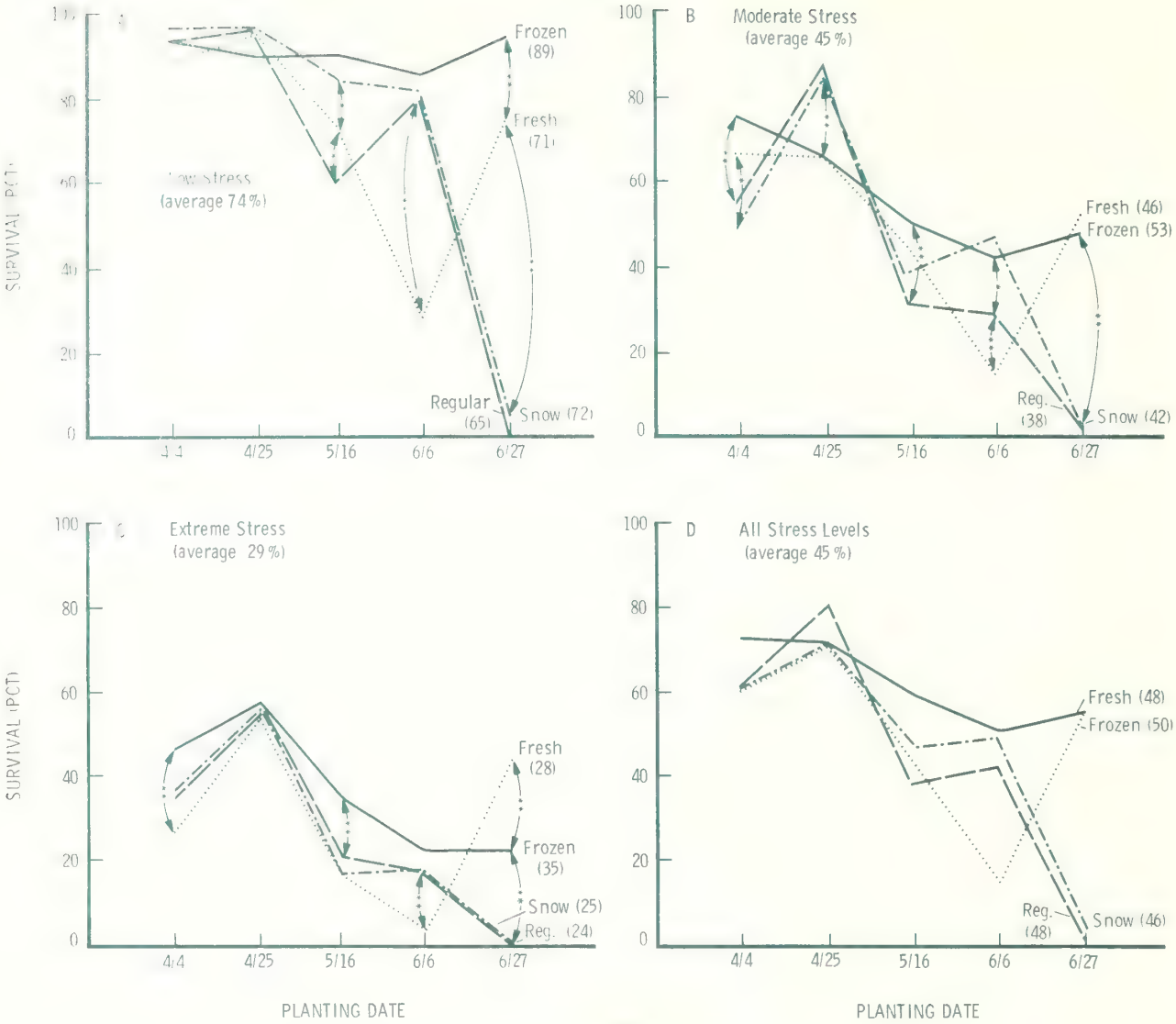

Figure 4.—First-season survival of western larch planting stock under four storage regimes, planted throughout the spring season. Figures in parentheses are average survivals over all planting dates. Significance differences attributable to storage are shown by * and ** (p = 0.05 and 0.01, respectively) and connecting arrows.

PHASE II. FIELD SURVIVAL AND GROWTH TESTS, 1973

While the 1972 moisture stress plot evaluation of the storage regimes and planting dates provided some valuable leads, testing under field conditions was needed to verify trends. The validity of the moisture stress plot technique also needed testing, especially when planting date was a study variable. Consequently, a small, single-season field test was installed on the Coeur d'Alene National Forest in 1973.

Methods

The same three species (Engelmann spruce, lodgepole pine, and western larch) were tested. Storage treatments were frozen, refrigerated, and fresh, all conducted in the same manner as in the 1972 study. Snow cache storage was omitted in the interest of economy—we felt that the technique already had been adequately field tested. Stock for overwinter storage was lifted between November 27 and December 1, 1972, preconditioned at 34° to 38° F (1° to 3° C) until December 7, then packed in 4-mil polyethylene bags, sealed, and placed in 28° F (-2° C) storage until removed for planting. All trees for regular refrigerated storage were lifted on March 19, 1973, packed in polyethylene-lined Kraft bags, and placed in 34° to 38° F (1° to 3° C) storage. All frozen stock was removed from storage 4 to 5 days prior to planting and held at 34° to 38° F (1° to 3° C) until the day of planting. Fresh stock was lifted the day before planting (table 6).

A total of 3,600 trees were planted, 1,200 of each species, in 100-tree lots, each with a specific treatment/species/planting date combination. Each lot was planted in two 50-tree rows separated by the other rows of species and treatments for that planting date. Spacing of trees was approximately 3 ft by 3 ft (1 m by 1 m). All trees were hand planted in auger-drilled holes. Each tree was staked and identified to allow accurate survival checks.

The study site provided uniformity of soil, aspect, and site preparation treatment. The area is approximately 8 miles east of

Table 6.—Length of nursery stock storage, in days, prior to planting, 1972–73

Planting date, 1973	Storage method and length of storage		
	Refrigerated	Frozen	Fresh
	Days		
April 18	30	140[1]	None
May 9	51	161	None
May 30	72	182	None
June 20	93	203	None

[1]Approximate, seedlings were lifted between November 27 and December 1, 1972 (135 to 139 days prior to April 18)

Coeur d'Alene, Idaho. It was logged in 1971, slashed, and prescribed broadcast burned in 1972. Burning was quite complete with all small slash consumed; a number of small logs on the ground were charred and not completely burned. The site is typical of the grand fir/pachistima habitat type (Daubenmire and Daubenmire 1968). West and north aspects were represented. Western larch and lodgepole pine were planted in one block on a uniform west aspect while the spruce was planted on a northerly aspect.

The summer of 1973 was extremely dry and hot compared to normal weather for the area (fig. 5). April through August precipitation was 51 percent of normal. Such weather was favorable for the field test because application of a high degree of moisture stress to the seedlings was desirable.

Survival was checked at the end of the first and third growing seasons (1973 and 1975). The total height of sample trees (every third survivor) was measured in the fall of 1975 to the nearest inch. Third-year survival, third-year height, and stem production (stem length produced per 100 planted trees) were analyzed by standard analysis of variance procedures for a factorial design. Species was included in the analysis as a main effect variable. Results of the analysis are shown in figures 6 through 14. Analysis of variance statistics are summarized in tables 7 through 9.

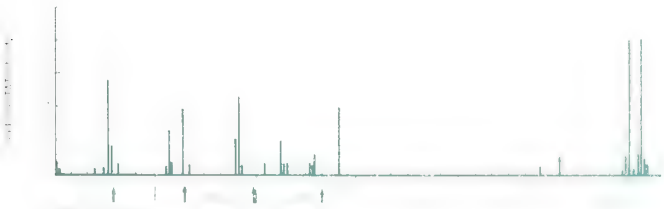

Figure 5.—Growing season precipitation, 1973, Coeur d'Alene, Idaho.

Results

ENGELMANN SPRUCE

Survival (fig. 6).—Average overall survival of spruce was 58 percent, significantly lower than survival of larch and lodgepole pine. This probably doesn't reflect true spruce potential, since the site was marginal for spruce. Survival ranged from 91 percent to 29 percent with a general decline as the planting season progressed. With an average survival of 82 percent, the April 18 planting survival was significantly better than the survival of the May 9 planting (62 percent survival) which was significantly better than the two later plantings (44 percent and 45 percent survival). For all planting dates survival was best with refrigerated (65 percent) and frozen (61 percent) stock. Fresh [illegible] survival. The survival of the May 9 plantings was probably depressed by an unusually warm, [illegible] plots.

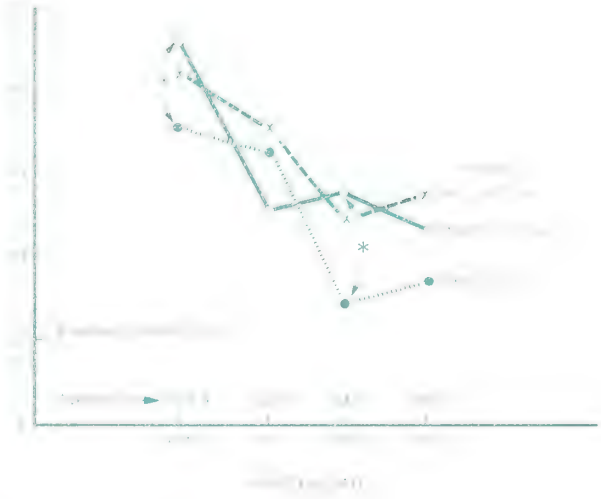

Figure 6.—Effects of storage regime and planting date on third-year survival of field-planted Engelmann spruce stock. Average survival percentages (in a row for planting date and, for storage treatment, in a column) followed by the same letter are not significantly different (p 0.05). Survival percentage levels, within a planting date, connected by arrows with an accompanying asterisk are significantly different (p 0.05).

Table 7.—Analysis of variance for survival, 1973 field trials

Source	DF	MS	F	Prob. < F
Replication	1	3.1250	1407	0 7110
Species	2	549 0556	24 7203**	0001
Storage	2	218 0556	9 8176**	.0007
Planting date	2	1,089.9398	49.0727**	0001
Species X storage	4	35.2639	1 5877	1984
Species X planting date	6	105 6481	4 7566*	0015
Storage X planting date	6	54 4259	2 4504*	0435
Species X storage X planting date	12	42.8009	1.9270	0648
Error	35	22.2107		

*Significant at the 95 percent level of confidence
**Significant at the 99 percent level of confidence

Table 8.—Analysis of variance for plant height, 1973 field trials

Source	DF	MS	F	Prob. < F
Replication	1	4.0139	0.7453	0.6019
Species	2	1,339.1885	248.6608**	.0001
Storage	2	38.2001	7.0930*	.0029
Planting date	3	137.7046	25.5690**	.0001
Species X storage	4	16.8481	3.1284*	.0263
Species X planting date	6	33.2164	6.1676*	.0003
Storage X planting date	6	6.9492	1.2903	.2866
Species X storage X planting date	12	5.0360	.9351	.5247
Error	35			

*Significant at the 95 percent level of confidence.
**Significant at the 99 percent level of confidence.

Table 9.—Analysis of variance for stem production, 1973 field trials

Source	DF	MS	F	Prob. < F
Replication	1	0.9239	0.1040	0.7475
Species	2	780.3405	87.8789**	.0001
Storage	2	127.3136	14.3376**	.0001
Planting date	3	451.0427	50.7947**	.0001
Species X storage	4	25.1816	2.8358*	.0383
Species X planting date	6	65.4484	7.3705**	.0001
Storage X planting date	6	24.9826	2.8134*	.0241
Species X storage X planting date	12	14.5019	1.6331	.1271
Error	35	310.7904	8,8797	

*Significant at the 95 percent level of confidence.
**Significant at the 99 percent level of confidence.

Growth (fig. 7).—Three years after planting, the average height of the surviving spruce trees was 15 inches (38.10 cm), ranging from 11 inches (27.94 cm) to 18 inches (45.72 cm). For all storage treatments, trees from the April 18 planting were taller than trees planted on June 20 (17 inches [43.18 cm] vs. 13 inches [33.02 cm]). There was no significant difference in the average height that could be attributed to storage treatment.

Stem production (fig. 8).—Planting date strongly influenced spruce stem production. Over the 3-year period, average production per 100 planted trees ranged from 116 ft (35.36 m) for the April 18 planting to 49 ft (14.93 m) for the June 20 planting. Production extremes varied from 35 ft (10.67 m) for fresh stock planted on May 30 to 135 ft (41.15 m) for frozen stock planted on April 18. Storage treatment, averaged over all planting dates, also had a significant influence on productivity, with fresh stock producing much less (59 ft [17.98 m]) than either frozen (77 ft [23.47 m]) or refrigerated (85 ft [25.91 m]) stock.

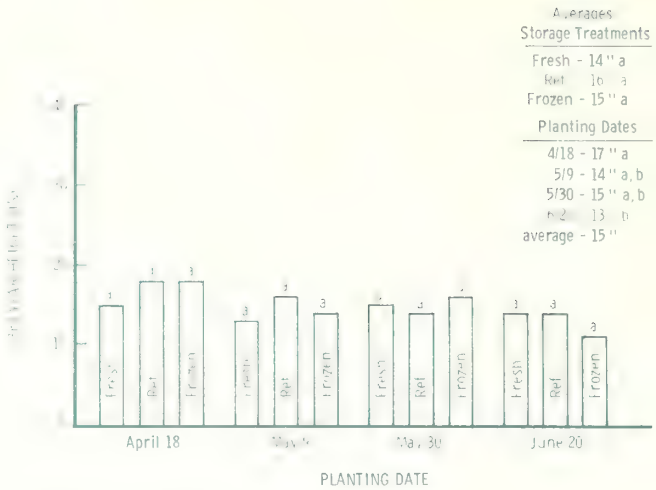

Figure 7.—Effects of storage regime and planting date on third-year height of field-planted Engelmann spruce stock. Columns, within a planting date group, topped by the same letter are not significantly different (p = 0.05). Averages, of storage treatments or planting dates, followed by the same letter are not significantly different (p = 0.05).

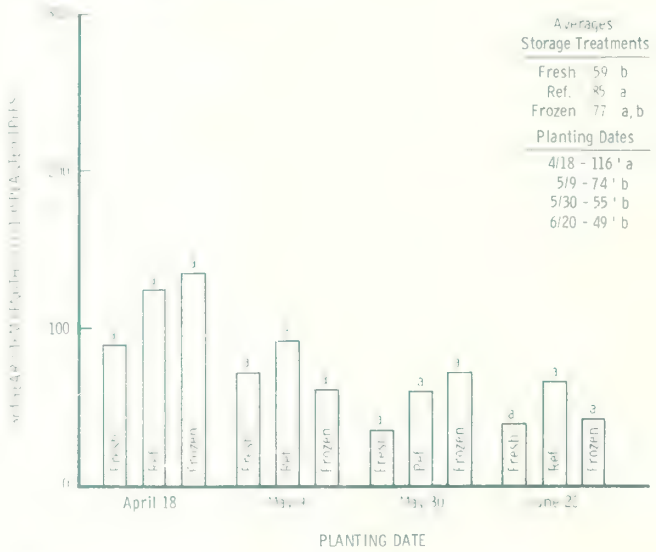

Figure 8.—Effects of storage regime and planting date on third-year stem production of field-planted Engelmann spruce stock. Columns, within a planting date group, topped by the same letter are not significantly different (p = 0.05). Averages, of storage treatments or planting dates, followed by the same letter are not significantly different (p = 0.05).

ODGEPOLE PINE

Survival (fig. 9).—Average lodgepole pine survival was [illegible] ent, and ranged from a low of 51 percent to a high of 90 [illegible] ent. Average survival of [illegible] ng dates was over 80 percent, significantly better than [illegible] f fresh stock (69 percent). This difference [illegible] vely poor survival of fresh stock planted on May 9 [illegible] une 20. Survival declined as the plantings were delayed, but [illegible] ecline was not as severe as it was [illegible] ig. 12).

Growth (fig. 10).—The 3-year height of lodgepole pine aver ged 21 inches (53.34 cm) and ranged from 17 inches (43.18 [illegible] 25 inches [illegible] aller (23 inches [58.42 cm]) than the fresh stock (20 inches 50.80 cm]), but [illegible] 21 inches [53.34 cm]). Stock planted on June 20 was 5 to [illegible] inches (12.70 to 15.24 cm) shorter than trees planted ea[illegible] he planting season.

Stem production (fig. 11).—Lodgepole pine averaged 140 ft 42.67 m) of stem production per 100 planted trees in the 3-year eriod, ranging from 70 ft (21.33 m) to 190 ft (57.91 m). When otals, by treatment, for all planting dates were averaged, [illegible] rated stock production was highest (160 ft [48.77 m]) and fresh tock the lowest (112 ft [34.14 m]). Frozen stock averaged 145 ft 44.19 m) of stem growth per 100 planted trees. Production [illegible] resh stock was definitely inferior to that from refrigerated and rozen stock for all except the April 18 planting. Stem produc- ion for the June 20 planting (89 ft [27.13 m]) was considerably elow that for earlier plantings (135–173 ft [41.15–52.73 m]).

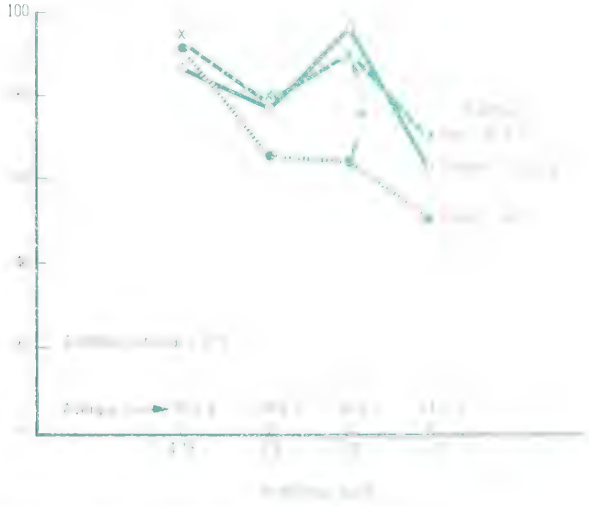

Figure 9.—Effects of storage regime and planting date on third-year survival of field-planted lodgepole pine stock. Average survival percentages (in a row for planting date and, for storage treatment, in a column) followed by the same letter are not significantly different (p = 0.05). Survival percentage levels, within a planting date, connected by arrows with an accompanying asterisk are significantly different (p = 0.05).

Figure 10.—[illegible]

Figure 11.—[illegible] Columns, within a planting date group, topped [illegible] ments or planting [illegible] are not significantly [illegible]

Survival (fig. 12).—The overall survival of western larch after 3 years was 65 percent, ranging from 33 percent to 94 percent. Both storage method and planting date have had a strong effect upon survival. For all planting dates the larch stored over winter in frozen condition survived better (71 percent) than either fresh or refrigerated stock (both 62 percent), but these differences were not statistically significant. Survival of the April 18 planting (87 percent) was significantly better than all other plantings; survival of the June 20 planting (39 percent) was significantly poorer than all others.

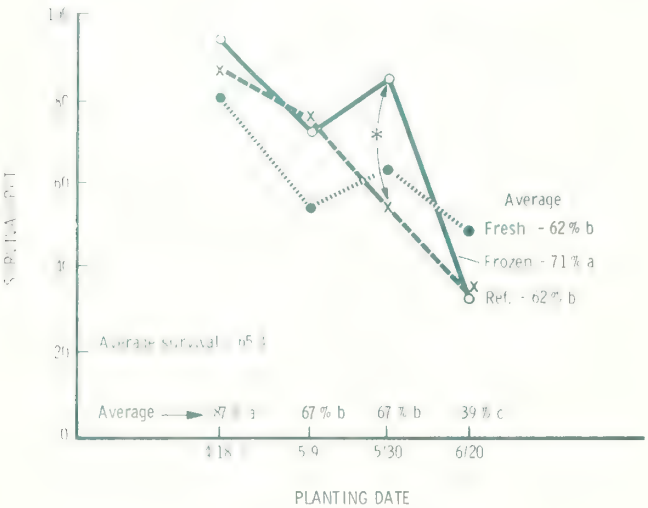

Figure 12.—Effects of storage regime and planting date on third-year survival of field-planted western larch stock. Average survival percentages (in a row for planting date and, for storage treatment, in a column) followed by the same letter are not significantly different (p = 0.05). Survival percentage levels, within a planting date, connected by arrows with an accompanying asterisk are significantly different (p = 0.05).

Growth (fig. 13).—Growth averaged 30 inches (76.20 cm) for all storage and planting date treatment combinations, with a range from 21 inches (53.34 cm) to 37 inches (93.98 cm). For all planting dates, frozen stock grew best (33 inches [83.82 cm]) and fresh stock grew poorest (27 inches [68.58 cm]). Planting date had an even stronger influence. Growth ranged from 32 to 36 inches (81.28 to 91.44 cm) for the April 18 and May 9 plantings, to 23 inches (58.42 cm) for the late June planting. Frozen stock consistently had the greatest third year height, and fresh stock was almost as consistently the shortest after 3 years. The effects of late planting in reduced height growth were more pronounced with fresh and refrigerated storage stock than with the frozen stock.

Stem production (fig. 14).—Larch averaged 168 ft (51.20 m) of stem production per 100 planted trees, and ranged from 278 ft (84.73 m) to 59 ft (17.98 m). When stem production was averaged over all planting dates, frozen stock outproduced refrigerated and fresh stock by a wide margin (201 ft [61.28 m] vs. 162 ft [49.38 m] and 141 ft [42.97 m], respectively). Averaged over all storage treatments, growth ranged from 232 ft (70.71 m) for the April 18 planting, to 74 ft (22.55 m) for the June 20 planting.

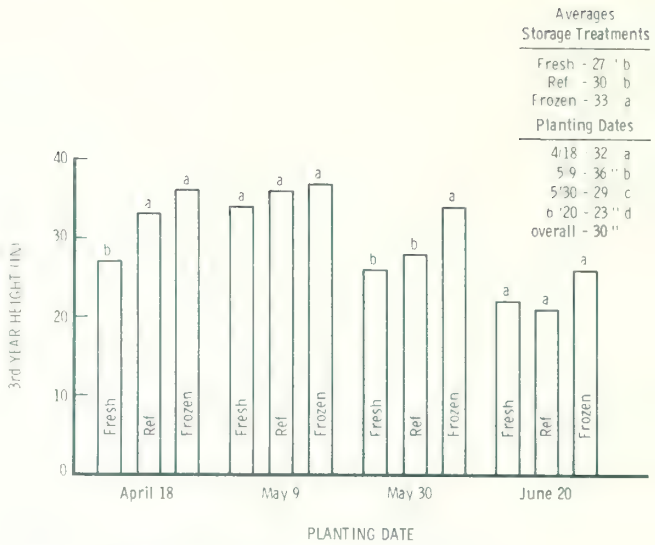

Figure 13.—Effects of storage regime and planting date on third-year height of field-planted western larch stock. Columns, within a planting date group, topped by the same letter are not significantly different (p = 0.05). Averages, of storage treatments or planting dates, followed by the same letter are not significantly different (p = 0.05).

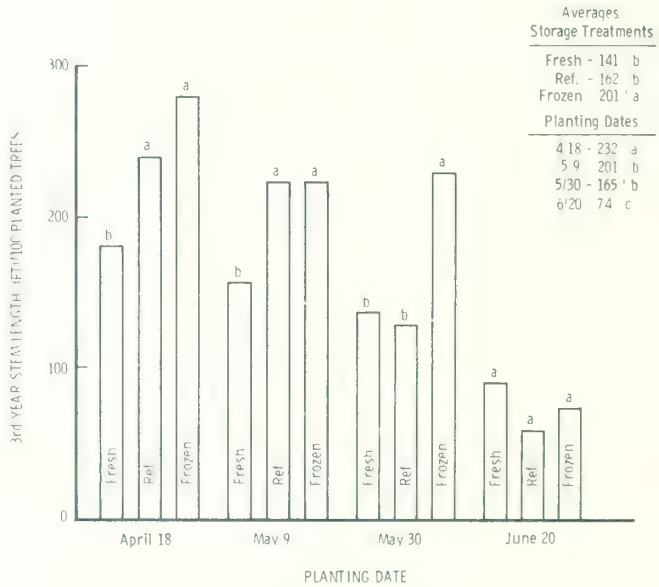

Figure 14.—Effects of storage regime and planting date on third-year stem production of field-planted western larch stock. Columns, within a planting date group, topped by the same letter are not significantly different (p = 0.05). Averages, of storage treatments or planting dates, followed by the same letter are not significantly different (p = 0.05).

Discussion

Results from both tests reported on here show that overwinter storage of planting stock at subfreezing temperatures results in survival and growth rates equal to or better than those obtained with conventional spring lift-cold storage procedures. In only a few situations was the survival of frozen stock significantly less than that of regular stock. Moisture stress plot test results were not completely verified by the field tests, however. In the field test, survival of late planted frozen and fresh stock did not exceed the survival of regular stock as in the moisture stress plot test. The difference in results can probably be attributed to the failure of the stress plot test to provide for decreasing soil moisture supply for the later planting. It was thought that keeping the stress plots at relatively high soil moisture levels until July 1 would emulate natural precipitation and soil moisture conditions in the field. Either this was not true, or the postplanting soil moisture depletion in the field was more rapid than in the stress plots. Of course, both factors could have contributed to the differences.

Because of this difference, the stress technique as used here is not recommended for tests that involve variations in planting date. A stress plot test using a modified physical arrangement and improved soil moisture monitoring and control is feasible, however.

Operationally, the frozen storage technique has great potential value for spreading nursery work, especially stock lifting and packing, over a longer time span. This could result in increased efficiency of operation and better utilization of nursery facilities. Furthermore, seedlings can be lifted in a fully dormant condition and stored at temperatures which effectively retard fungal activity. Complete satisfaction of chilling requirements may be an additional benefit.

Seedlings which must be stored until high elevation sites open late in the planting season also store better frozen. Freshly lifted stock, which has neared or reached the end of the initial rapid shoot elongation period in the spring, has good survival potential only if unusually good soil moisture and atmospheric conditions prevail following planting.

RECOMMENDATIONS

1. [illegible] tural overwinter conditions. It is feasible and offers important advantages over other storage methods, especially for stock [illegible] planted late in the planting season.

2. Regardless of the storage regime used, early plan[illegible] in better survival and subsequent growth. Fall lifting [illegible] winter storage should facilitate early planting, especially in years when weather conditions preclude early lifting of stock at the nursery.

3. Frozen storage is probably extendable to other western [illegible] ifers. Validation of this assumption is needed.

4. Planting freshly lifted stock late in the planting season, after most [illegible] ible, but operationally difficult. Such planting [illegible] but fresh stock of this sort must be replanted very soon after lifting to avoid severe mortality. Such stock must be treated delicately in the interval between lifting and planting. It is better to plant dormant trees early in the season for both growth and survival.

5. More study is needed to determine the effects of fall lifting dates on the survival and growth potential of stock stored over winter and on methods to determine when stock is physiologically ready for lifting. Until information is available, it is recommended that stock not be lifted prior to November 1 or until there is suitable evidence that the stock is "dormant" and that food reserves are at a high level. The current practice at the Coeur d'Alene Nursery involves testing the plants' activity status using the oscilloscope technique described by Ferguson and others (1975). Plants are not lifted until 2 weeks after they show a "dormant" oscilloscope trace.

6. The described frozen storage may provide for more complete satisfaction of the "chilling requirements" of Engelmann spruce buds leading to more normal bud break and shoot growth than that obtained with other lifting and storage procedures.

7. Methods and studies of overwinter cold storage of nursery stock are well documented and the procedure can be made operational in most cases if cold storage facilities are available.

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12 p.

In two studies in northern [illegible]
under a variety of regimes and planted throughout th [illegible]
season. Planting date had the stro [illegible]
with early plantings performing better than late plantings.

KEYWORDS: conifer seedlings, lifting, storage, planting date

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Research Paper
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January 1983

Variation in Estimates of Fire Intervals: A Closer Look at Fire History on the Bitterroot National Forest

Stephen F. Arno and Terry D. Petersen

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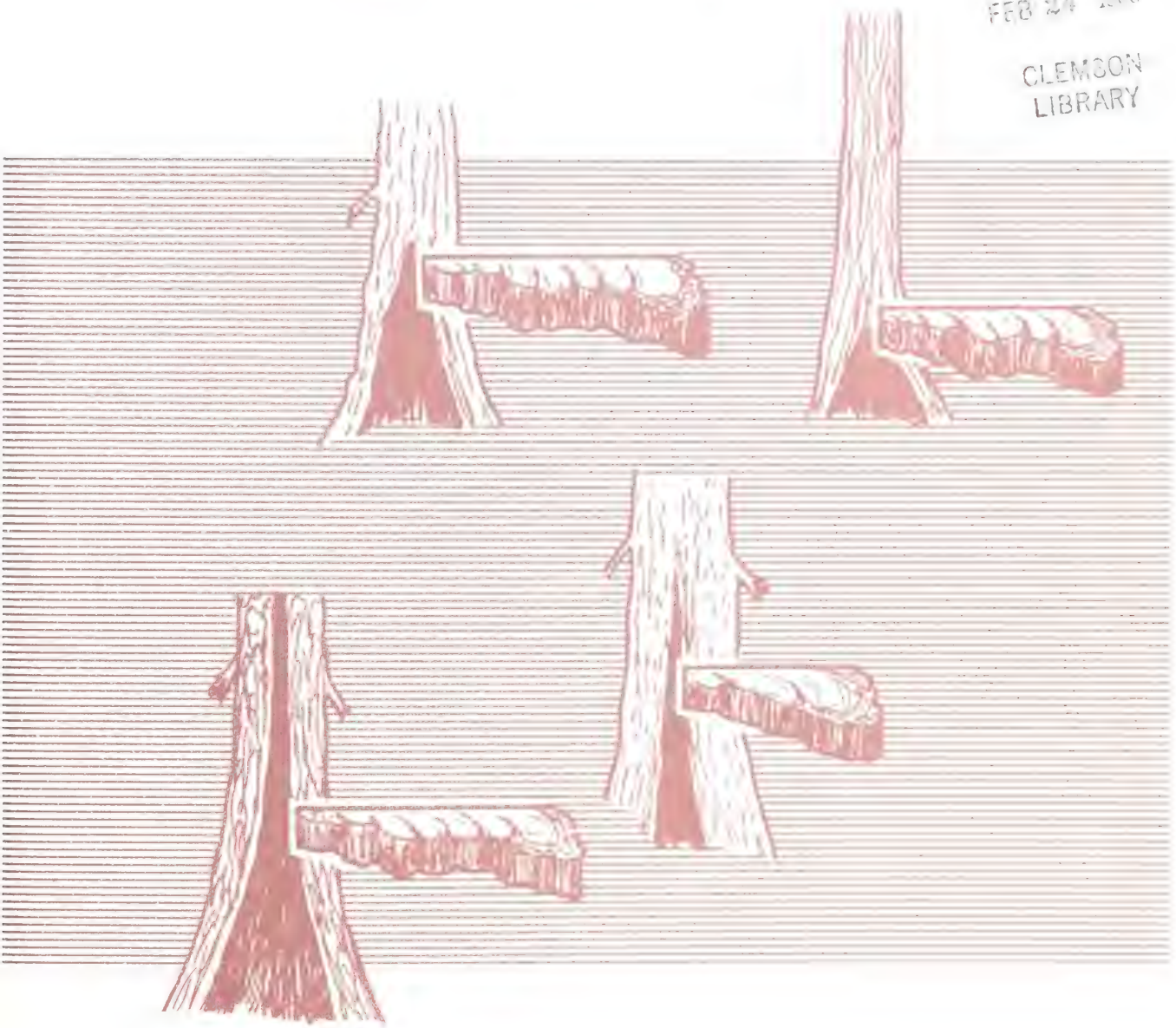

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TERRY D. PETERSEN assisted in the analysis of data and preparation of this paper while employed by the Fire Effects research work unit in 1981. He earned a B.S. in forest management from Oklahoma State University and an M.S. in forest ecology from Oregon State University in 1980. He is currently a research forester with Champion International Corporation in Milltown, Mont.

RESEARCH SUMMARY

Variations in estimates of intervals between wildfires (occurring between the years 1600 and 1910) are examined in relation to the size of fire history sample units. This comparison is based on re-analysis of data from an earlier study, including 904 fire scars from 172 trees on three study areas on the Bitterroot National Forest, Mont. Fire history evidence is examined within sample units of five sizes, ranging from a point on the ground (records from a single tree) to those contained on all sample trees in a large stand (200 to 800 acres; 80 to 320 hectares).

Mean fire intervals are compared for each size class of sample units within each of five forest zones for the three study areas. Mean fire intervals for larger units are shortest because they designate the occurrence of fire somewhere within the unit. Mean fire intervals are generally longest for the point on the ground (or single tree), but such intervals are often incomplete because light fires often failed to scar individual trees in their path. Also, in areas having long fire intervals it is difficult to reconstruct intervals from a single tree because at least two fire scars are necessary. Therefore, construction of a master fire chronology based on records from several trees is generally advantageous.

The authors recommend basing calculations of fire intervals on small- to medium-sized sample units—between 1 and 100 acres (0.4 and 40 hectares) depending upon the type of forest studied. They also stress the importance of interpreting the size of sample units when comparing fire intervals from different studies.

United States
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Forest Service

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Stephen F. Arno and Terry D. Petersen

INTRODUCTION

Anyone who has studied fire history over a sizeable area of land has faced the problem of reporting findings in terms that will be most meaningful for land managers and scientists. Researchers have commonly reported the mean **fire interval** (interval between fires) during the 250- or 300-year period before fire suppression began in the early 1900's. Mean fire intervals can be calculated for a continuum of stand sizes, however, ranging from entire watersheds to single points (individual trees).

The mean fire interval for a large area is often calculated by combining all fire years that have been identified at sample points (individual fire-scarred trees) within it into a master fire chronology covering the entire area. (Fire history terminology used here is based on Romme 1980). Mean fire intervals calculated from a master fire chronology probably tend to be shortened as the study area becomes larger and more sample trees (points) are included. This reduction of fire intervals with increasingly large sample areas would result primarily because many fires burned only small portions of the area. Thus when such fires (fire years) are incorporated into a master fire chronology, it must be remembered that the data (including mean fire intervals) represent only the occurrences of fire somewhere within the sample area. Another problem with calculating mean fire intervals for large areas is that such areas often include several different habitats that have different fire histories. A fire-interval statistic based on large areas, therefore, is of limited use for characterizing the fire history in smaller stands.

Conversely, estimates based on fire scars from a single tree can be expected to overestimate the length of mean fire intervals. This occurs because light surface fires often fail to inflict a new wound even on previously scarred trees (Houston 1973; Arno 1976; Dieterich 1980). On the other hand, records from a single tree might include scars from tiny spot fires having little ecological significance. The opportunity to accept only evidence of spreading fires, represented by fire scar dates occurring on two or more sample trees in a stand, is not available when calculations are based on an individual tree.

With these considerations in mind, several authors (for example, Tande 1979; Arno 1980; Dieterich 1980; Barrett 1980; Davis 1980) have reported fire intervals for small areas, each representing a relatively homogeneous site and stand. This approach [illegible] more sample trees as well as ages of fire-initiated tree regeneration (such as distinct age-classes of shade-intolerant species requiring fire for establishment) from the same location. But, how large of an area should be sampled to provide the most useful characterization of fire history?

The following re-analysis of fire history data from the Bitterroot National Forest has been made to help address this question [illegible] vide more refined fire history data for use in that area.

METHODS

Fire scars on trees and fire-initiated tree regeneration (age-classes) were sampled on three study areas (Onehorse, Tolan, and West Fork) on the Bitterroot National Forest in western Montana (fig. 1). These data were used as the basis for a previous report (Arno 1976), which presented fire intervals only for relatively large stands, generally 100 to 800 acres (40 to 320 hectares) in size.

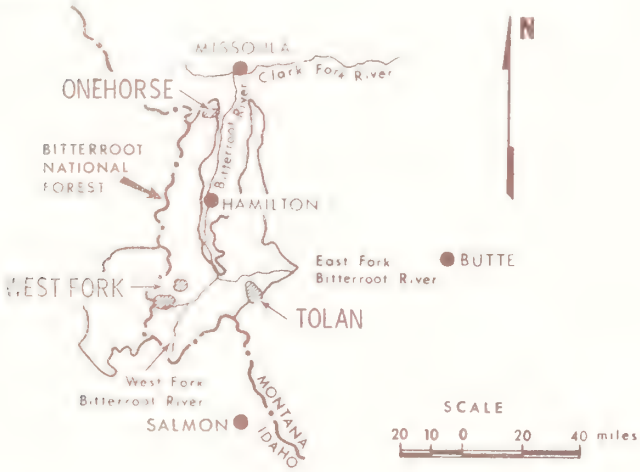


Figure 1.—Location of the three study areas.

More recently, it was reasoned that this data base (including 904 individual fire scars from 172 trees plus age-class information) could be inspected to observe the effect of sample-area size on length of fire intervals. For the current study, we inspected the topographic maps showing sample tree locations for all three study areas and designated sample units of five sizes. We superimposed these sizes of sample units on the maps so as to efficiently include all concentrations of sample trees occupying similar topographic positions and habitat types. Thus, to the extent that the distribution of sampled trees and topography allowed, we designated sample units of the following sizes within a given forest zone:

Large stand	=	200 to 800 acres (80 to 320 ha)
Small stand	=	50 to 100 acres (20 to 40 ha)
Grove	=	10 to 15 acres (4 to 6 ha)
Cluster	=	about 1 acre (about ½ ha)
Single tree	=	point on the ground.

We included the maximum number of sample trees in units of any given size, as if we were carrying out new field studies and were seeking the most complete fire history information obtainable within each size class of sample unit (fig. 2, A and B).

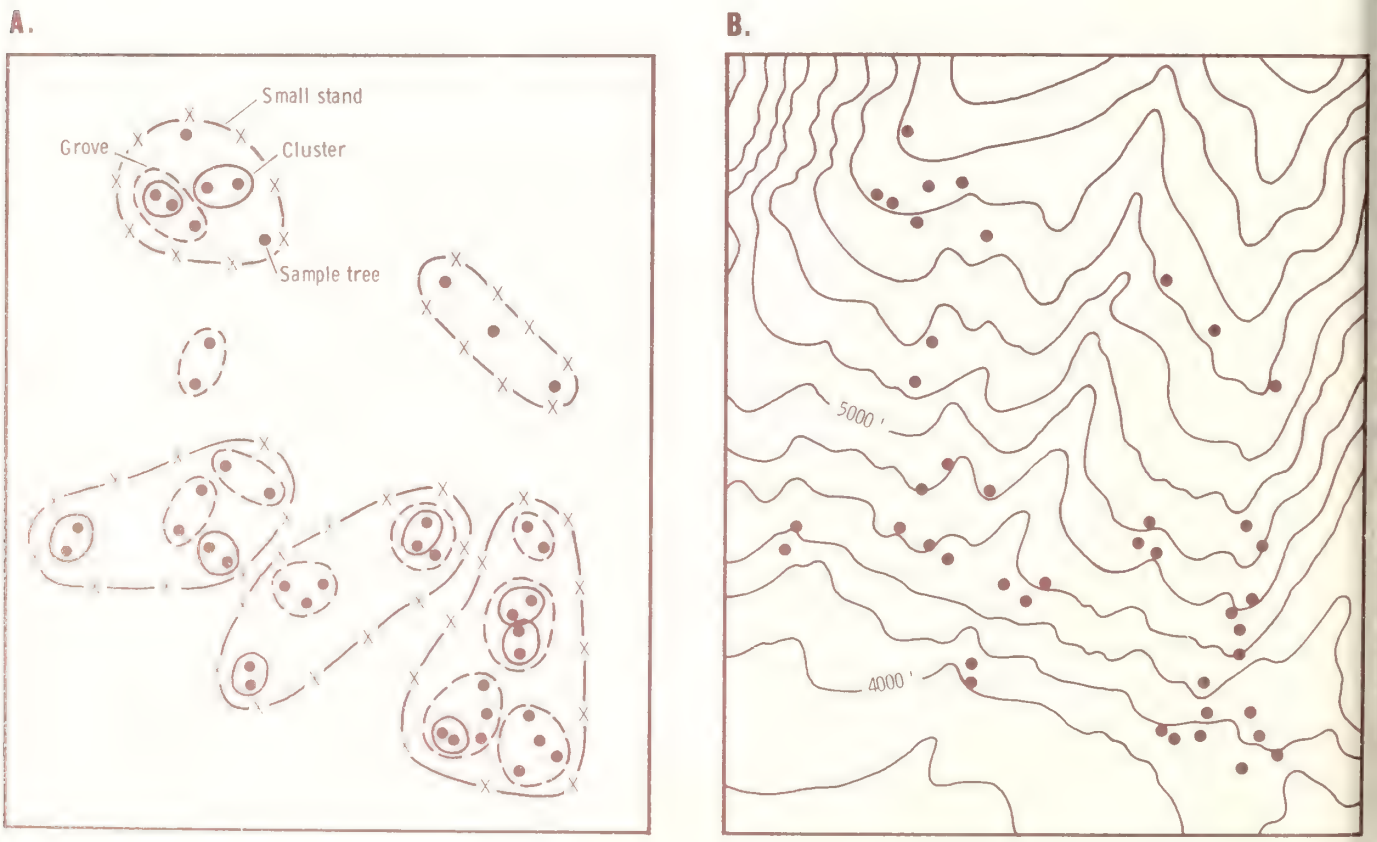


Figure 2.—A. Location and arrangement of sample units and sample trees within the large stand in the montane zone at the Onehorse study area. B. Topographic map of same area showing sample trees.

The following forest zones were used for stratifying results (representative habitat types for each zone are listed in table 1):

1. Valley edge—the lowest slopes (3,800 to 4,800 ft; 1 160 to 1 460 m elevation), predominantly ponderosa pine (*Pinus ponderosa*) forest.
2. Montane slopes— lower to midelevation forests (4,200 to 6,200 ft; 1 280 to 1 890 m) of seral ponderosa pine and potential-climax Douglas-fir (*Pseudotsuga menziesii*).
3. Moist canyon—a moist variant of montane slopes, primarily with seral western larch (*Larix occidentalis*) and potential-climax grand fir (*Abies grandis*).
4. Lower subalpine—midelevation forests (6,000 to [illegible] (*Abies lasiocarpa*).
5. [illegible] (*Pinus albicaulis*) and potential-climax sub[illegible] (*Abies lasiocarpa*).

[illegible] on the cumulative fire history records within sample u[illegible] each size. This mean fire interval is an estimate of the a[illegible] number of years between fires (other than tiny spot fires, not

Table 1.—Fire intervals for the period 1735 to 1900 on the th[illegible] (1976), are based on all fire years ide[illegible] at type units (stands).

Habitat type groups (potential climax) (Pfister and others, 1977)	Descriptive location	General elevations	Dominant trees with continued fire exclusion (most abundant tree first)	[illegible] before 1900 (most abundant tree first)	Onehorse (No. of trees)	Onehorse (min-max interval)	Tolan (No. of trees)	Tolan Mean fire (min-max interval)	West Fork (No. of stands (No. of trees)	West Fork Mean [illegible] interval (min-max interval)
		Feet								
1. *Pinus ponderosa/ Festuca idahoensis* *Pseudotsuga* [illegible] *Agropyron* [illegible] *Pseudotsuga/ Calamagrostis, P. ponderosa* phase	Valley edge	[illegible]	[illegible] pine	[illegible]	1 (11)	6 (2-20)	[illegible]	[illegible]	[illegible]	[illegible]
2. *Pseudotsuga/ Physocarpus malvaceus* *Pseudotsuga/ Calamagrostis* (except *Calamagrostis* phase) *Pseudotsuga/ Symphoricarpos albus* *Pseudotsuga/ Vaccinium globulare* (except *Xerophyllum* phase)	Montane slopes	4,200-6,200	Douglas-fir	[illegible]	[illegible]	[illegible]	(11)	(4-29)	[illegible]	19 [illegible]
3. *Abies grandis* habitat types	Moist canyon	4,300-4,700	[illegible]	western larch [illegible]	(7)	(3-32)	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible] *Calamagrostis, Calamagrostis* phase *Pseudotsuga/ Vaccinium globulare, Xerophyllum* phase *Abies lasiocarpa/ Xerophyllum tenax* *Abies lasiocarpa/ Menziesia* [illegible] *Abies lasiocarpa/ Linnaea borealis*	Lower subalpine slopes	6,700-7,500	subalpine fir	[illegible] Douglas fir	[illegible]	[illegible]	3	[illegible]	3	28
5. *Abies lasiocarpa/ Luzula hitchcockii* *Abies lasiocarpa* *Pinus albicaulis/ Vaccinium scoparium* *Pinus albicaulis-Abies lasiocarpa*	Upper subalpine slopes	7,500-8,600	subalpine fir whitebark pine	[illegible]	(3)	[illegible]	2	30	2	[illegible]

scarring any other sample trees in the forest zone) occurring within, but not necessarily spreading throughout a given sample unit. These data were actually the **grand means**, or mean of the mean fire intervals, for all units of a given size. Single-tree estimates were based on the tree in every cluster having the most complete fire-scar records—namely, the shortest mean interval between fire scars. The mean of the mean (grand mean) fire intervals for all of these single trees in a forest zone was calculated. In a few instances, age-class data from intolerant trees provided evidence of an additional (earlier) fire not detected by fire scars. Such evidence was added to the fire record for all units (except single tree) in which that age class was detected.

The following approach was used to lengthen the period of record which serves as the basis for estimating mean, median, and maximum fire intervals. Arno (1976) used the period 1735 to 1900 because detailed records were available for all trees during that time, and in about 1910 fire suppression activities were begun. This relatively short period was used for that report largely to hold the time period constant for comparison of all study-area units. Inspection of the earliest fire scar records—going back to about the year 1500 at Onehorse and 1600 at Tolan and West Fork—however, showed no marked change in the frequency of fire other than that attributable to diminishing numbers of fire-recording trees (see Arno 1976, table A–4 and figure 2). Thus, in order to utilize the longest pre-fire suppression record of fire history for each stand, we counted all fire intervals, starting with the earliest recorded fire in each unit and extending to the last fire prior to 1910. The rationale for this sort of "floating" beginning date is that fire resistant trees become highly susceptible to being scarred by fires only when they have been scarred for the first time (Arno and Sneck 1977).

Calculations of mean fire intervals were then made as shown in table 2. (Median and maximum intervals were calculated from the same basic data.) For each sample unit, we listed all pre–1910 fire years recorded on any of the trees. The number of intervals between fires (one less than the number of fires) was then divided into the total number of years between the first and last fires. Part B (table 2) shows another approach we used to lengthen the fire record. These fire data are from an upper subalpine unit at Tolan, which had five fires between 1679 and 1811 (mean interval of 33 years) and none thereafter, although suppression did not begin until about 1910. We added the interval from the last fire until 1910 in this and other cases where its inclusion would lengthen the mean interval (adjusted mean interval 46 years). Although we do not know what the length of this final interval would have been had fire suppression not been started in 1910, we know that the interval would have been at least 99 years in this example case and that its addition should improve the estimate of the true mean.

Table 2.—A. Example of fire interval calculations for a small stand (at the Tolan Creek Study Area; upper subalpine slopes). All sample trees are lodgepole pine. (The 1932 cambium date for tree 17 coincides with a mountain pine beetle epidemic that also killed other fire-scarred trees in this area.)

Sample tree number				Composite fire scar chronology
13	16	17[1]	18	
Dates[2]				
1975c	1975c	1932c	1975c	
1871fs				1871
	1842fs			1842
1785fs	1785fs	1785fs	1785fs	1785
1757fs	1757fs		1757fs	1757
1752fs				1752
1648p	1648p		1664p	
		1632fs		1632
		1595fs		1595
		1526p		

Pre-1910 fire record: 1871
− 1595

mean fire interval = 276 years ÷ 6 fire intervals
= 46 years (range: 5–120 years)

B. Example of the approach used to lengthen the fire-interval record by adding the year 1910 (start of fire suppression) when its inclusion would lengthen the mean interval

	Composite fire scar chronology	
Added date	1910	
	1811fs	
	1785fs	Adjusted
Mean interval	1752fs	mean interval
33 years	1743fs	46 years
	1679fs	

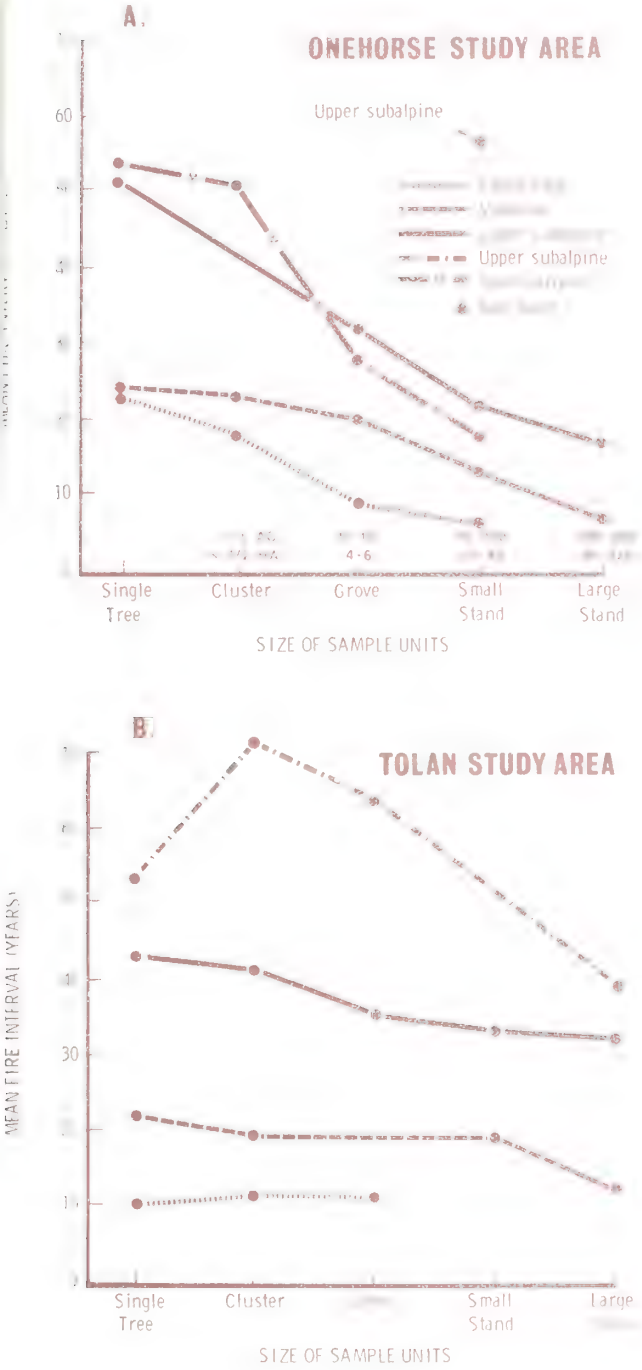
[1]Snag
[2]c = cambium date; fs = fire scar date; p = pith date.

RESULTS AND DISCUSSION

Mean fire intervals were inversely related to size of the sample units. These relationships are shown for all three study areas in figure 3, A, B, and C, where each line represents mean fire intervals for different sizes of units within the same forest zone. The mean fire interval is shortest for large stands within any forest zone. (This overall statistic is actually the grand mean or mean of the mean fire intervals for all sample units of a given size by forest zone.) This mean fire interval for large stands is an estimate of the average number of years between fires (other than tiny spot fires) occurring within, but not necessarily spreading throughout, a given 200- to 800-acre (80-to 320-hectare) stand.

Conversely, the mean fire interval for any forest zone is generally longest when based on fire histories at points on the [illegible] complete records). The grand mean fire interval is somewhat [illegible] terval) from each cluster of trees. This interval remained similar [illegible] sistent reduction in the fire interval occurs when the sample unit is enlarged to the large stand category.

A notable exception to these general trends occurs in the upper subalpine data at Tolan (fig. 3), where the single tree mean is shorter than those of the cluster and grove units. This results



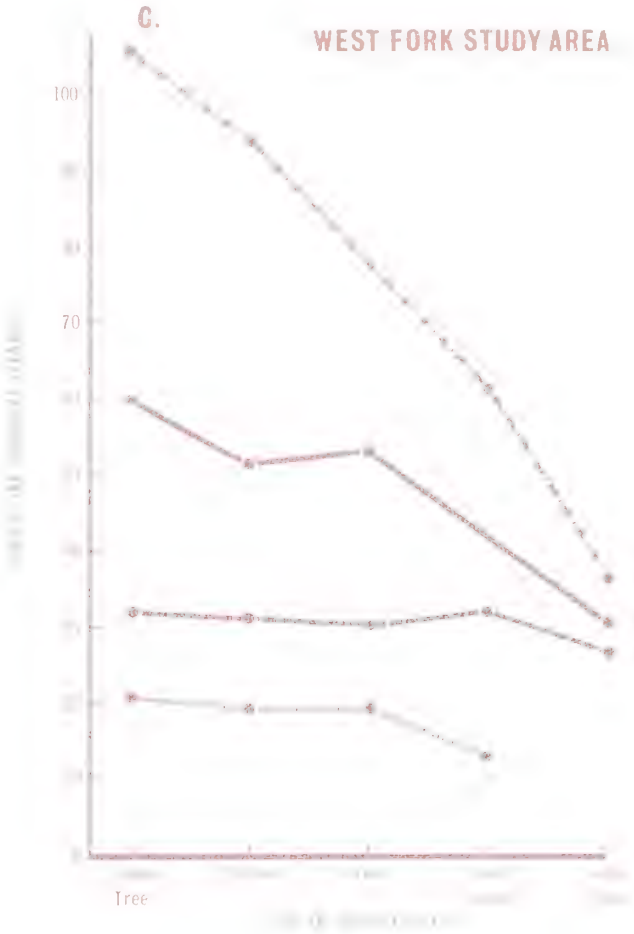


Figure 3.—Mean fire intervals in relation to size of sample units

from shrinkage of the data base when the sample size is reduced from clusters to single trees. In this case, six **clusters** were available, but only four of them had an individual tree with more than one fire scar (table 3). A minimum of two fire scars is necessary for designating a fire interval on an individual tree. Thus, there was no means of estimating the fire interval for the two points on the ground probably having the longest intervals. This problem of defining fire intervals on individual trees, based on scars of at least two fires, would tend to be more critical in areas having long fire intervals. Prior to 1900, when wildland fires were seldom suppressed, fires undoubtedly burned incompletely and in a patchy pattern through many stands when weather or fuels were moist. Such fires would have scarred trees sporadically, as has occurred on some recent lightning fires that have been allowed to burn under surveillance in northern Idaho—for example, the 1979 Smith Mountain fire on the Kootenai National Forest (observed by Arno).

Table 4 presents median, mean, and maximum pre-1910 fire intervals for all size classes of sample units in each of the three study areas. Some of these mean intervals differ substantially from those listed in the earlier report (table 1) because of the additional stratification by sample-unit size and the effort to utilize the longest pre-1910 period of record as the basis for calculations. We feel that this new approach represents a significant refinement for potential users.

Table 3 lists the numbers of sample units by size class and forest zone. Some of the mean fire intervals were obviously based on small amounts of data. Still, the relatively consistent trends in the data seem significant.

In fact, these data probably reflect a **conservative** estimate of the effect of sample unit size on fire intervals. This conservatism occurs because spatial arrangement of our field samples (gathered long before this analysis was visualized) did not allow for a complete representation of consecutively enlarged sample units in the same locations. A more definitive examination of this effect could possibly be made using the data from several detailed fire history studies, such as Tande (1979), Heinselman (1973), Romme (1979), Davis (1980), and Madany and West (1980). Or, a new, detailed field study might be necessary, using an approach that would allow for analysis of progressively larger subsets of data and documentation of the effect of sample unit size on fire intervals. This would be a large undertaking if it were to apply to several forest zones or types.

Figure 4 compares mean fire intervals among the three study areas for the middle-sized grove (10 to 15 acres [4 to 6 hectares] sample unit) category. It is evident that the three areas had similar patterns of fire intervals in relation to forest zones. This and other data (table 4) show that fire intervals for a given forest zone were generally similar at Onehorse and Tolan, but usually somewhat longer at West Fork.[1] Overall, these findings illustrate the relatively frequent occurrence of fires in all forest zones, with the limited exception of the upper subalpine forest. As explained in Arno (1976), much of this pre-1910 fire occurred as surface fires that left a considerable amount of surviving overstory timber.

Figure 5 shows the distribution of fire intervals by interval length in small stands in the valley edge and montane zones at Onehorse. This skewed distribution is typical of these two forest zones, and it illustrates why the median fire interval for lower elevation forests is less than the mean at all three study areas (table 4). Also, this distribution emphasizes the unusualness of the maximum intervals reported in table 4. Strikingly, the number of years since the last fire in most units (except in the upper subalpine zone) is greater than the maximum fire intervals detected prior to 1910.

Table 3.—Number of sample units for the five size classes in each of three study areas on the Bitterroot National Forest. Data are presented by forest zone

Area and forest zone	Size class of sample units				
	Single tree	Cluster	Grove	Small stand	Large stand
ONEHORSE STUDY AREA					
Valley edge	3	2	2	1	-
Montane slopes	9	9	13	5	1
Moist canyon	2	2	3	1	-
Lower subalpine	2	-	3	2	1
Upper subalpine	-	-	-	1	-
TOLAN STUDY AREA					
Valley edge	1	1	1	-	-
Montane slopes	4	4	-	4	2
Lower subalpine	3	3	4	4	2
Upper subalpine	4	6	4	-	2
WEST FORK STUDY AREA					
Valley edge	1	1	1	1	-
Montane slopes	5	4	7	8	3
Lower subalpine	3	3	4	-	2
Upper subalpine	6	6	-	4	2

[1]A possible explanation for this is that the Onehorse area is immediately adjacent to the main Bitterroot Valley grassland where Indian-caused fire seem to have been frequent (Barrett 1981). Tolan and West Fork are more remote, but Tolan is a drier area where fuels may be receptive to burning during a longer season.

Table 4.—Median, mean, and maximum pre-1910 fire intervals [illegible] sample units in each of three study areas on the Bitterroot National Forest. Find [illegible] forest zone. Median interval is in italics; mean is in bold type; maximum is in pare[illegible]

Area and Forest zone	Size class of sample units: Single tree (point on the ground)	Cluster (about 1 acre)			Grove (10-15 acres)			Small stand (50-100 acres)			Large stand (200-800 acres)		
ONEHORSE STUDY AREA													
Valley edge	[illegible]	*20*	[illegible]	(34)	[illegible]	9	(20)		[illegible]	(20)			
Montane slopes	24	*20*	23	[illegible]	*16*	20	(52)	[illegible]	13	(36)	[illegible]	7	(36)
Moist canyon	54	*50*	[illegible]	(71)	*30*	28	(51)	[illegible]	[illegible]	(33)			
Lower subalpine	51				*34*	32	(38)	*24*	22	(26)	*18*	17	(33)
Upper subalpine								[illegible]	[illegible]	(92)			
TOLAN STUDY AREA													
Valley edge	11	*11*	12	(30)	[illegible]	12	(30)						
Montane slopes	23	*20*	20	(41)				*19*	20	(50)	[illegible]	[illegible]	(38)
Lower subalpine	44	*44*	42	(50)	*36*	[illegible]	(54)	*33*	34	(56)	*30*	33	(63)
Upper subalpine	54	*69*	[illegible]	(102)	*56*	[illegible]	(103)				*40*	40	(71)
WEST FORK STUDY AREA													
Valley edge	21	*17*	19	(30)	[illegible]	19	(30)	*10*	[illegible]	(22)			
Montane slopes	32	*31*	31	(52)	*27*	30	(56)	*30*	[illegible]	(58)	*23*	26	(52)
Lower subalpine	60	*54*	51	(64)	*54*	53	(62)				*30*	30	(43)
Upper subalpine	106	*96*	[illegible]	(109)				*68*	61	(90)	*35*	36	(82)

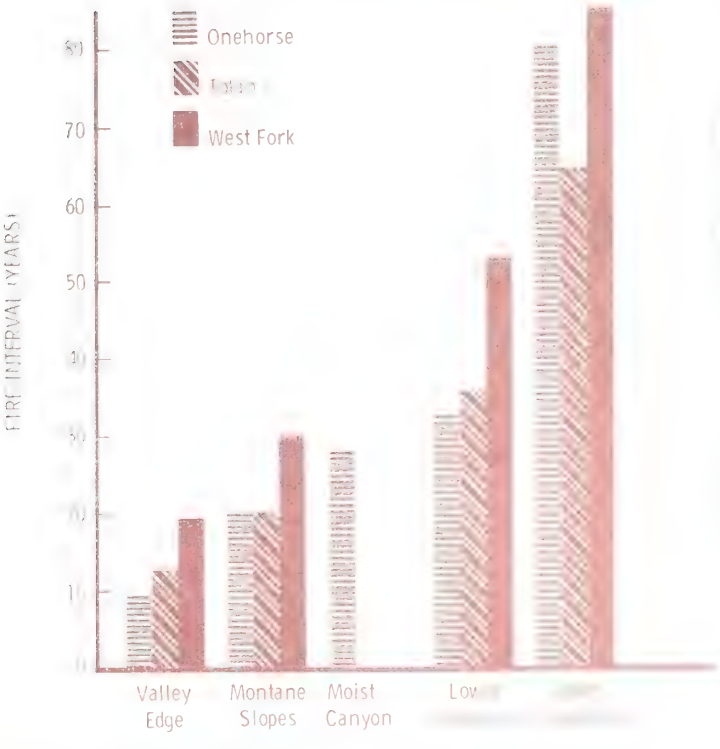


Figure 4.—Mean fire intervals in groves (10 to 15 acre sample units) for different forest zones in the three study areas.

Figure 5.—Percentage distribution of fire intervals by interval length for small stands on the Valley Edge and Montane Slopes at Onehorse Study Area. The Valley Edge zone had [illegible] in one small stand between 1668 and 1889. Montane Sl[illegible] 133 fire intervals in 5 small stands between 1496 and 1904.

CONCLUSIONS

Recommendations for Fire History Research

It is apparent from this analysis that there are substantial variations in length of fire intervals related to sample unit size. The most reasonable approach when making comparisons is to use units of similar size and preferably those representing one of the intermediate categories—cluster, grove, or small stand. Units of these sizes allow adequate sampling intensity for detection of nearly all light surface fires, but are generally small enough to serve as a basis for site-specific fire history information. We suggest that in future studies the size of units be clearly specified and interpreted in comparisons to other studies. Smaller unit size (cluster, for example) may be desirable in types where trees (such as ponderosa pine or whitebark pine) are long-lived and readily fire scarred, whereas larger units (grove or small stand, for example) may be necessary for piecing together a more complete fire history in forest types where the oldest surviving trees are more scattered (for example, lodgepole pine) or more resistant to scarring (for example, western larch or Douglas-fir).

Fire History Implications on the Bitterroot National Forest

Study results show that the current long-term absence of fire contrasts strongly with pre-1900 fire intervals, especially in lower and middle-elevation forests. Lack of fire has allowed an undesirable buildup of dead and living (ladder) fuels in many stands, particularly in the ponderosa pine and Douglas-fir forests. It has also fostered chronic overstocking of unmerchantable trees, reducing tree vigor. Extensive buildups of dwarf mistletoe (*Arceuthobium douglasii*) in Douglas-fir and western budworm (*Choristoneura occidentalis*) in Douglas-fir, spruce, and true firs seem to be related to these changes in stand conditions (Fellin 1979). Certainly the pre-1900 fire regimen stimulated production of herbaceous or shrubby plants, useful as forage for wildlife and livestock. These are some reasons suggesting that reintroduction of fire under the right conditions could enhance values of various forest resources.

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Arno, Stephen F., Petersen, Terr[illegible] timates of fire intervals: a closer look at fire history on [illegible] INT-301. Ogden, UT: U.S. De[illegible] mountain Forest and Range [illegible] 8 p.

The authors examine variation in the length of mean intervals between fires (occurring between the years 1600 and 1910) in sample units of various sizes, ranging from a point on the ground (single tree) to a large stand (200 to 800 acres; 80 to 320 hectares). Recommendations are made regarding appropriate sizes of sample units for fire history studies.

KEYWORDS: fire ecology, fire history, fire frequency, forest fire, forest ecology

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Research Paper
INT-302

February 1983

Monitoring the Condition of Wilderness Campsites

David N. Cole

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RESEARCH SUMMARY

Information on the distribution and severity of wilderness campsite impacts is necessary for planning purposes. Monitoring of campsite conditions will also allow managers to evaluate change in campsite condition and how such changes relate to management actions. Existing campsite monitoring systems are based on visual estimates of impact, measurements of impact, or photographs. The most useful systems (1) evaluate a number of meaningful parameters, (2) record each of these parameters separately, and (3) use as precise techniques as management can afford and still be able to inventory all sites. Estimation techniques will probably have to be used in most wilderness areas where funds are short and campsites are numerous. Suggestions for how to develop such a system are provided. Keys to success include adequate training so techniques are used in a consistent manner, quantitative category definitions, and documenting site locations so they can be reassessed in the future.

United States
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Research Paper
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Monitoring the Condition of Wilderness Campsites

David N. Cole

INTRODUCTION

Recreational use of wilderness and backcountry areas inevitably leaves an imprint on natural environments intended for preservation. Wilderness use affects trails, meadows, and lakeshores, but impacts are usually most pronounced on campsites. Where wilderness managers have judged that impacts exceeded acceptable levels, they have often taken such actions as closing severely deteriorated sites, diverting campers to less-used areas, or confining use to designated sites. Too often these actions are taken without the benefit of comprehensive campsite condition data. Consequently, it has been impossible to evaluate the effects of these actions on either impacted sites or adjacent areas which are currently undamaged.

In recent years, managers have been under pressure to improve the sophistication and accountability of wilderness management. Regulations in the National Forest Management Act of 1978 specifically require Forest Service wilderness managers to limit and distribute visitor use in such a way that natural conditions are largely unimpaired and to monitor the response of the wilderness resource to these actions. Much of this effort must be focused on campsites, the places that are most severely altered by recreational use and among which visitor use may have to be limited and distributed.

Unfortunately, funding for the collection of data needed for wilderness management is sorely lacking compared to funding available for collecting data used in the management of other resources, such as timber. Access to most wilderness acreage is poor; motor vehicles are not allowed and many remote areas are not even penetrated by trails. Moreover, many areas have thousands of sites that must be inventoried.

This paper discusses desirable characteristics of a backcountry campsite inventory and monitoring system, evaluates existing methods, and provides suggestions for developing a system that builds on the strong points of existing techniques.

DESIRABLE CHARACTERISTICS

[illegible] meaningful information about changes that have already occurred on campsites. This tells the manager how widespread and severe recreational impacts have been and, therefore, how [illegible] evaluated.

[illegible] measures of impact are utilized; (2) measurement techniques are reliable and sensitive; (3) costs are not too high to prohibit an inventory of all sites; and (4) measurement units can be precisely relocated.

The value of the information collected will depend on how [illegible] of a campsite is not a measure of impact. It is so highly variable under natural conditions that it must be compared to an estimate of the original cover on the site before it provides a [illegible]

Variables selected for use also need to be applicable to sites that have received radically different types or amounts [illegible] and sites in different environmental settings. Simi[illegible] even in very different situations, should reflect simil[illegible] of change. This can be achieved mo[illegible] information on a number of different para[illegible] parameters in a single measure of site condition, importa[illegible] formation will be lost if the [illegible] such as size of the campsite, is [illegible] flexibility of changing their minds about the relative importance of any given measure of campsite condition.

The second characteristic is reliability; assessment techniques must be sufficiently precise to allow independent observers to reach similar conclusions about site condition. This depends on precise explanation of techniques and consistent training of evaluators. Assessment techniques must also be sensitive enough to detect managerially relevant differences between sites and changes over time.

Managers must always make a tradeoff between reliability/sensitivity and cost. More precise techniques take more time and this may become prohibitive if sites are numerous. Assuming the primary objective is to characterize the distribution of impacted sites and be able to detect major changes, managers would do best to use as precise techniques as they can afford and still be able to inventory all sites. It might also be desirable, however, to take more precise measurements on a subsample of campsites. This practice would allow managers to detect more subtle changes and to more accurately relate such changes to use levels, environmental conditions, or other variables that might affect amount of impact. For example, such measurements have been taken in Sequoia and Kings Canyon National Parks and in Great Smoky Mountains National Park (Bratton and others 1978).

Finally, in order to monitor changes over time, it is important to document the exact location of the areal unit on which the original measurements were taken. This might be the entire campsite, square plots, line transects, or any other sampling unit.

EVALUATION OF EXISTING SYSTEMS

Perhaps the most widely used campsite inventory system is the Code-A-Site system originally proposed by Hendee and others (1976). Important information about each site is recorded on edgepunch cards, which facilitate data retrieval and manipulation. It is the method of collecting and storing information rather than the type of information collected that is unique to this system. In fact, much of the information on the Code-A-Site form is irrelevant in backcountry. Several managers have modified the cards, however, to more adequately achieve their data needs. In Olympic National Park, the edgepunch cards have been completely reprinted with different types of information (Schreiner and Moorhead 1979). Managers of the Selway-Bitterroot Wilderness merely developed an overlay, with more relevant information to use with the original cards developed by Hendee's group. Campsite condition data—my specific concern in this paper—can be stored on Code-A-Site forms or in any other convenient manner.

Most existing campsite monitoring systems fall into one of three basic types. In one type, campsites are given a single condition rating which is usually based on visual estimates of impact. In other systems, a number of measurements are taken, each of which can be repeated and used as a separate measure of change. Photographic techniques are the basis of other systems.

Estimates of General Condition

The original Code-A-Site form (Hendee and others 1976) only asks for a judgment of whether the impact of previous use has been extreme, heavy, moderate, or light. These terms are not defined. Consequently, it is impossible to compare the condition of sites rated by different people or to accurately assess changes on the site at a later date; the system lacks the characteristic of reliability or precision.

This problem can be alleviated by defining different levels of impact. Frissell (1978) developed a method of rating campsite condition that recognizes the following condition classes: (1) "Ground vegetation flattened but not permanently injured. Minimal physical change except for possibly a simple rock fireplace"; (2) "Ground vegetation worn away around fireplace or center of activity"; (3) "Ground vegetation lost on most of the site, but humus and litter still present in all but a few areas"; (4) "Bare mineral soil widespread. Tree roots exposed on the surface"; and (5) "Soil erosion obvious. Trees reduced in vigor or dead" (fig. 1a and b). One of the Code-A-Site modifications made by managers of the Selway-Bitterroot Wilderness was to define extreme, heavy, moderate, and light levels of impact on the basis of these same easily recognized indicators of change.

A.

B.

Figure 1.—Examples of campsites with condition class ratings of (A) 2 and (B) 4 (Frissell 1978).

Either of these "condition class" systems provides the manager with a rapid, inexpensive technique for rating campsites and the data generated is relatively precise. Although the use of quick visual estimates of parameters, such as bare ground, is less precise than more time-consuming measurement techniques, the ratings of trained independent observers can be sufficiently consistent and sensitive to make reliable comparisons of campsite condition possible.

The few parameters chosen by Frissell provide a useful summary measure of campsite condition for the landscapes in which the system was developed—coniferous forests in cool climates, where litter accumulation is great, growing seasons are short, and ground vegetation is highly sensitive to disturbance.

In many other environments, howev

no trees, ratings must be based on only one or two parameters. Moreover, the significance of the changes associated with a condition such as "ground vegetation lost on

undergrowth of coniferous forests and al

where recovery of damaged vegetation m

(Willard and Marr 1971).

This problem was substan

developed for use in Sequoia and Kings Canyon National Parks

rapid estimates of easily recognized indicator

eight separate parameters are used: vegetation

tion composition, campsite area, area of the barren core, campsite development, presence of organic litter and duff, number of access (social) trails, and number of tree mutilations. The mean value for all the ratings that apply to the site—number of tree mutilations, for example, is not applied to

sites—becomes the campsite rating. Even if a couple of parameters cannot be applied to the site, the rating should still be valid because it is based on a large number of other

The major problem with this system is tha

become experienced, only the site's overall conditio

recorded; individual parameters are only noted on

of sites. Consequently, disaggregation of the data is impossible. It will not be possible to evaluate future changes in indi

parameters, such as campsite area or degree of dev

Perhaps more importantly, wilderness managers are locked into the current system of weighting each of the eight paran

equally. If each parameter had been recorded

managers at a later date could delete parameters th

sidered unimportant or change the weighting

reevaluating each site.

The reason data were aggregated in Sequoia and Kings Canyon National Parks was that there were too many c

take the time or storage space to fill out a separat

each site. Over 7,400 campsites have been inventoried in the two Parks (Parsons and MacLeod 1980). This large number of campsites is uncommon. In the more common situation of fewer campsites, it would be worth the addition

record each parameter separately, with a separate form

site.

Measurements

Several areas use measurements rather than visual estimates. Such systems are more costly—it takes more time to rate each site—but precision is higher (fig. 2). The information contained in such ratings, however, is not necessarily more meaningful. Olympic National Park, for example, rat

bare ground radius, the mean distance to "the first live plant" along eight transects radiating from the campsite

(Schreiner and Moorhead 1979). In the Eagle Cap Wilderness, bare ground radius proved to be a less useful predic

campsite condition than Frissell's less precise, but

ingful condition class (Cole 1982).

This problem can be alleviated by measuring more parameters. In the Olympic National Park system, the number of

by horses are also noted. The managers of Great Smoky Mountains National Park measure the area, on and around each site, of the following "disturbances": bare rock, mud, slop

sion, bare soil, leaf litter, trampled vegetation, firewood clear

ing, tree damage, and trash dispersal (Bratton and other

In the Selway-Bitterroot Wilderness, tree mutilations are recorded, as is the amount of bare mineral soil, litter-covered soil, and vegetation along each of eight permanent line transects.

Provided that meaningful parameters are measured and appropriate sampling methods are used, measurements are prefer able to estimates. They reduce the potential for observer bias

such a system is high, however, and where there are a large number of campsites, the increased precision may not be worth the expense. Where the number of campsites is low

Smoky Mountains National Park, for example, had only 113 legal sites and another 289 illegal sites—measurement

be a worthwhile investment.

It is important that meaningful and comparable evaluations

and to evaluate changes in the condition of more lightly im

change are so much greater here than on more heavily impacted sites. If funding is insufficient to take measuremen

than to only take measurements on some of the sites.

Photographs

A number of areas have made replicable photopoints the basis of their monitoring system. In a system used in the Selway-Bitterroot Wilderness, 360°-panorama photo mosaics (fig. 3) are taken from permanent points located near the center of each site (Walker 1968). Photographs have generally not proven to be reliable substitutes for field measurements or estimates of parameters, such as ground cover vegetation or exposed mineral soil. Patches of sunlight and shade often make interpretation of the ground cover difficult, and it is seldom possible to distinguish features beyond the closest trees. As supplementary documentation they can be quite useful, however. They can help identify the site for future reassessments, record campsite features not measured in the field, and provide a visual supplement to the data collected in the field.

Figure 3.—Panorama photo mosaics have been used in the Selway-Bitterroot Wilderness.

RECOMMENDATIONS

From the preceding discussion, the most useful campsite inventory and monitoring system appears to be one that (1) evaluates a number of meaningful parameters, (2) records each of these parameters separately, and (3) uses as precise techniques as management can afford and still be able to inventory all sites.

Choosing the Precision Level

This choice must be made primarily on the basis of available funding and the number of campsites. The frequency of periodic reassessments of the sites should also be considered.

Where the number of campsites is low and/or funding is high, precise measurement techniques utilizing such sampling units as permanent quadrats, belt transects, or line transects can be afforded and are preferred. Measurements taken on a subsample of sites might also provide a useful supplement to an estimation system in areas which cannot afford to take measurements on all sites.

In most areas a measurement system, which usually involves spending an hour or more on each site, is too time-consuming and costly. In this case, visual estimates can be used in place of measurements. Precision and sensitivity are reduced but the resulting ratings should be adequate to meet most management needs, if each parameter is independently recorded. Using such a system, the amount of time spent on each site could be less than 10 minutes.

Finally, if there are so many campsites in an area that even 10 minutes per site is too much, campsites can be given a single aggregate rating. As mentioned above, this severely limits flexibility in the future use of the data. In the system in use at Sequoia and Kings Canyon National Parks, a couple of minutes per site is all that is necessary.

Choosing Parameters

Managers should choose parameters that reflect unique types of impact occurring in the area they administer. Types of impact that are most likely to conflict with management objectives should be given high priority. In general, the types of impact that occur on campsites do not differ greatly from place to place. Many of the same parameters are used by Parsons and MacLeod (1980) in California, by Frissell (1978) in Minnesota and Montana, and by Schreiner and Moorhead (1979) in Washington. Most other areas will probably also find these same parameters to be a useful list of possibilities.

Based on work in a number of wilderness areas, but particularly in the Eagle Cap Wilderness in Oregon, I have developed a campsite monitoring system that incorporates many of these same parameters. The system uses visual estimates on the assumption that this type will be most useful in most areas. The following discussion describes suggested estimation techniques for each parameter. While these estimation techniques should be widely applicable, class definitions, which are also included, should vary greatly from place to place.

For example, I recently used this system in the Bob Marshall Wilderness in Montana, an area that receives heavy horse and outfitter use and which, in many locations, has few potential campsites. As a result of this type of use, most sites, when compared to those in the Eagle Cap Wilderness, are large, littered with horse manure, and have experienced severe tree damage and root exposure. Consequently, almost all sites received the worst ratings for camp area, cleanliness, damage to trees, and exposure of tree roots. Despite identical ratings, some of these sites were much worse than others. In order to provide ratings that identify the most severely impacted sites, I developed class definitions that were less stringent than those used in the Eagle Cap Wilderness. In like manner, managers of most areas should adapt the class definitions suggested in this paper to their unique situation.

CONDITION OF GROUND COVER VEGETATION

Loss of ground cover is one of the most prominent [illegible] that occurs on campsites. It is a prominent, early indicator [illegible] campsite [illegible] Estimates of percent cover are not useful in themselves because there is so much variability in the cover of undisturbed [illegible] Some system of relating [illegible] to that of the surroundings is needed.

My recommendation is to estimate the percent cover of campsite vegetation in one of the [illegible] to 5 percent, 6 to 25 percent, [illegible] percent, 51 to 75 percent, and 76 to 100 percent. With time and training this can be done consistently. It may be helpful to walk around the site and mentally average cover in different parts of the site. In cases where it is extremely difficult to choose between classes, make your best guess and then [illegible] to choose between. Make a [illegible] of the percent cover of the vegetation surrounding the site, keeping in mind that you are attempting to estimate what the cover of the site was before it was used as a campsite. This involves looking closely at places that are similar to the campsite in terms of rockiness, slope, canopy cover, and species composition, and looking at the vegetation in places protected from trampling. While this estimate is seldom simple to make, it can be done with practice.

Comparison of these two coverage class estimates can be used to give each site a rating from 1 (least impact) to 3 (most impact). A campsite with a vegetation cover that is two or more coverage classes less dense than that found offsite is assigned a rating of 3. For example, if the vegetation cover is 51 to 75 percent offsite and 6 to 25 percent onsite (two coverage classes less dense), the campsite will receive a rating of 3. Vegetation loss equivalent to one class is assigned a 2, and no loss is assigned a 1 (fig. 4).

Figure 4.—[illegible]

A measure of change in species composition would also be useful. This requires considerable judgment and training, however, and is particularly difficult to assess on campsites where essentially all vegetation has been lost. The Sequoia and Kings Canyon National Parks system utilizes this parameter, considering it to be inapplicable if the site has been totally devegetated. This can lead to worse ratings for a site with some highly dissimilar vegetation left than would be given to a completely denuded site. It might be better to merely note whether or not the vegetation left consists primarily of weedy invaders.

EXPOSURE OF BARE MINERAL SOIL

Recent studies have shown that the amount of mineral soil exposed on a site increases dramatically on more heavily used sites (Fichtler 1980; Cole 1982). Therefore, soil exposure is a particularly good indicator of campsite condition. As with the preceding parameter, it is possible to estimate coverage in the five coverage classes, both on the campsite and in a neighboring area. The vegetation and bare soil estimates can be made simultaneously. The same rating system can be used as well.

Bare mineral soil is more difficult to estimate than vegetation because there is usually a continuous gradation from twigs, leaves, and needles, through partially decomposed and decomposed litter to mineral soil. Moreover, on many campsites heavy trampling has arranged these materials in a highly intricate mosaic of litter and exposed soil. Where litter layers are thin and have obviously been displaced by recreational use, my estimates of bare soil have been high. Elsewhere I have been more conservative. Training and calibration of observers is particularly important with this parameter.

DAMAGE TO TREES

Trees on and adjacent to campsites frequently have had their lower branches broken, their boles hacked, and nails driven into them. In many cases, smaller trees have been cut down for firewood or tent poles. Standing snags have also been hacked and cut.

On sites which have trees either onsite or at their periphery, it is possible to rate this damage. The main problem is defining classes. Three classes can be defined as follows: (1) no more damage than some broken lower branches; (2) between one and seven tree mutilations (ax marks, scars, carvings, nails, cut stumps, and so on), no more than one of which is obtrusive; and (3) more than seven tree mutilations or more than one obtrusive mutilation. More than one mutilation can occur on a tree. Less stringent class definitions were necessary in the Bob Marshall Wilderness, where tree damage was severe. For comparative purposes at a later date, it is important to include brief notes on the size and location of the area to be reexamined and on the amount of different types of damage.

EXPOSURE OF TREE ROOTS

The number of trees with exposed roots has been found to increase along with amount of use as a result of soil compaction and erosion (Cole 1982). Root exposure is particularly pronounced on sites used by horse parties due to the practice of tying horses to trees.

This parameter, again, is only applicable to sites with trees onsite or at their periphery, and defining classes is difficult. I defined three classes as follows: (1) no trees with root exposure; (2) root exposure occurs, but on no more than three trees; and (3) root exposure on more than three trees (fig. 5). It is important to distinguish between natural root exposure in shallow soils and exposure of roots resulting from trampling. Training will lead to consistent judgments, and supplemental notes will facilitate future assessments of change.

Figure 5.—This campsite would receive a rating of 3 for tree root exposure and also for tree damage.

XTENT OF DEVELOPMENT

Developments include [illegible] structions. Both the number of developments and their obtrus veness need to be considered. While not indica [illegible] rast to the preceding four para [illegible] visitors.

I defined the following three [illegible] sting fire ring or well-developed sea [illegible] leveled tent pads, or other developments [illegible]

Figure 1.—[illegible] for development.

CLEANLINESS OF THE SITE

[illegible] and cleanliness were the most critical variables affecting the visitor's enjoyment of the site. Included here is the [illegible] charcoal, blackened logs, other remnants of campfires, lit [illegible] toilet paper, human waste, and horse man [illegible] the site.

Three classes can be defined [illegible] than scattered charcoal from on [illegible] remnants of more than one fire site or some litter or blackened logs; and (3) any horse manure, human waste, or toilet paper, or widespread litter, blackened [illegible] campfires. Include notes w [illegible]

TOTAL AREA OF THE CAMPSITE

This parameter can be measured with tape me [illegible] pacing. If the site is roughly circular, it is [illegible] average radius and use the formula f [illegible] the site is more rectangular, the product [illegible] width measurements is more appropriate. With [illegible] should quickly become easy to es [illegible] measurements. Include any satellite tent p [illegible]

[illegible]

I defined three clas [illegible]

[illegible] THE BARREN CORE

[illegible] the fir [illegible] tion in [illegible] barren core that [illegible] core in their work in [illegible]

I defined thre [illegible]

[illegible] TRAILS

[illegible] d from [illegible]

I defined three [illegible] or more than one well-developed trail.

Summary Ratings

[illegible] usually desiral [illegible] vidual ratings into a summar [illegible] easiest meth [illegible] change is of equal importa [illegible] alt the importance of the other parameters. Indi [illegible]

The d [illegible]

Campsite Number 67 Management Area Murray Lake

Vegetation Cover		Mineral Soil Cover	
Onsite 0-5%	Offsite 50-75%	Onsite 5-25%	Offsite 0-5%

Parameter	Notes	Rating	Weight	Product
Vegetation loss	Surviving plants mostly Juncus and Carex; no exotics	3	1.0	3.0
Bare soil increase	most of site covered by thin, disturbed litter layer	2	2.0	4.0
Tree damage	5 felled trees; 6 trunk scars	3	1.0	3.0
Root exposure	5 trees with exposed roots	3	2.0	6.0
Development	1 fire ring, 2 old fire sites, logs for sitting	3	0.5	1.5
Cleanliness	horse manure, some trash, widespread charcoal	3	0.5	1.5
Camp area	300 m²	3	2.0	6.0
Bare area	200 m²	3	1.0	3.0
Access trails	4 trails; 3 are well developed	3	1.0	3.0
	Total		11.0	31.0

Summary Rating 2.8

Comments Forested site easily visible from main trail. One of the first large, obvious sites for hikers coming up the East Fork of Lostine River. appears to be popular with horse as well as hiking parties. Damage is heavy, but the site appears to be stable. Effort should be made to keep the area as clean as possible

Date August 23 1980 Name David Cole

Figure 7.—Possible format for data collection form.

Photographs

A few photographs [illegible] and [illegible] will provide a useful supplement to field measurements. To be most useful, at least one photograph should include some feature of the campsite or its vicinity which can aid in relocating the site. When photographing forested sites, make use of cloud cover whenever possible, as patches of shade and sunlight make interpretation of the ground cover difficult. Moderately fast (high ASA) color print film is useful for most purposes. Color film is more sensitive to differences in ground cover than black and white, and prints, although bulkier than slides, are easier to refer to both in the field and in the office. Color film may tend to fade with age, however, suggesting that use [illegible] black and white film may be desirable for long-term comparisons.

The time of year and time of day should be noted on all photographs. If photographs taken in subsequent years are to be compared with any precision, it will also be necessary to record the precise location of the photopoint, distance and direction to subject, height of the camera above the ground, camera make and model, focal length of the lens, filter type, and film type. These conditions should be replicated to as great an extent as possible when subsequent photographs are taken. Reference as to whether the year has been unusually wet or dry, or whether snowmelt was late or early may also be important.

Future Reassessments

Periodically—perhaps every 5 years—all of these sites should be reexamined. Difficulties in relocating sites can be reduced if each site is located on a map or with a pinprick on an aerial photograph, and if a reference photo of each site is taken into the field. It is also important to document on maps or aerial photographs all areas that were and were not thoroughly searched for campsites. When additional sites are found, this will indicate whether these sites are new or were just missed in the earlier inventory.

USE OF CAMPSITE CONDITION DATA

Data on the condition of campsites provides information on [illegible] forms a basis for evaluating the "acceptability" of current conditions and for developing management [illegible] ns. It also serves as a baseline for a monitoring program.

[illegible] state that no campsites will be larger than 1,000 ft² or no campsites will have a summary rating [illegible] amining the inventory data, it will be possible to tell if current conditions meet these standards. If they do not, mitigating ac-[illegible]

The value of this approach is that it provides a coherent [illegible] also provides a definition, in the form of standards, of the wil- [illegible] manager is trying to provide. This approach makes it clear when a management response is [illegible] by whether conditions become acceptable in the future or not.

At this time (1981), few areas have developed formal standards. Consequently, it is not possible to evaluate the acceptability of current conditions. The data can, however, be used to document current conditions and to identify both the extent or [illegible] campsite impacts and sites where impacts are [illegible] ere. This will help in the development of man- [illegible] hether attention is given to the preservation of portions of the area that have not been highly disturbed or to the rehabilitation of particularly severe problem areas.

This information will become increasingly valuable with time. If campsites can be relocated and reassessed in a manner con- [illegible] nal assessment, it will be possible to identify trends in condition, of the whole area and of individual sites, and to relate these trends to changes in use characteristics and management actions. Having rated condition parameters separately, it will be possible to distinguish improvement in some parameters from deterioration in others. Such information should lead to an ever-increasing ability to meet management objectives established for backcountry campsites.

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Managers need information on the distribut[illegible] campsites and how this pattern of impact is c[illegible] discusses desirable characteristics of a wilder[illegible] itoring system, evaluates existing methods, ar[illegible] veloping a system that builds on the strong p[illegible]

KEYWORDS: monitoring, campsite, backcount[illegible] ecological impact

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**Intermountain
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Experiment Station
Ogden, UT 84401**

Research Paper
INT-303

February 1983

Assessing and Monitoring Backcountry Trail Conditions

David N. Cole

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THE AUTHOR

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RESEARCH SUMMARY

The costs of mitigating trail deterioration problems could be reduced through improved trail location and design and through improved monitoring of conditions. This paper describes assessment techniques with the potential for improving management of backcountry trails. Three types of assessment techniques are considered—replicable measurements, rapid surveys, and censuses. Sampling and measurement techniques are described for each, and the utility of the results is assessed.

To illustrate their application, specific techniques are applied to the Big Creek trail system in the Selway-Bitterroot Wilderness. Both repeated measures of the cross-sectional area of the trail and rapid surveys show that most of the trail system is stable and in good condition. Certain segments are in poor condition, however. An examination of the relationship between trail condition and site, design, and use characteristics indicated that poor location was the major cause of problems. A census of trail problems and associated site and design characteristics identified (1) vegetation and soil indicators to guide trail location, and (2) design techniques to avoid damage where poor locations cannot be bypassed.

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INTRODUCTION

Deteriorating trails are a common problem in wilderness and other backcountry areas. They detract from the major goals for such areas—to maintain natural conditions and to provide outstanding opportunities for wilderness recreation experiences. Large sums of money are spent every year to maintain, rebuild, and relocate trails. These costs could be greatly reduced if we could better predict where deterioration is likely to occur and how it can be minimized through trail location and design. Costs could be further reduced by monitoring trail conditions so that protective actions are taken before more costly remedial actions are necessary.

Physical deterioration of trails—for example, widening, deepening, and damage to the tread—is generally of more concern than vegetation change. Vegetation change is less obvious to visitors, is usually confined to about 3 ft (1 m) on either side of the trail (Dale and Weaver 1974; Cole 1979), and, most important, does not impair the trail's planned function as a transportation facility.

Several studies of the physical condition of trails have been undertaken (Cole and Schreiner 1981), from which potentially useful techniques for assessing current conditions and monitoring future changes have emerged. This paper presents various approaches and measures available and the types of information each can provide. To illustrate their application, specific techniques were applied to about 17 miles (27 km) of established trail in the Big Creek drainage of the Selway-Bitterroot Wilderness in Montana. Results of this case study provide an assessment of current conditions and the severity of ongoing deterioration, as well as guidelines for trail location and design. The paper concludes with a discussion of the usefulness of these techniques to managers.

TYPES OF ASSESSMENT TECHNIQUES

Available techniques can be conveniently grouped into three types: replicable measurements of a small sample of trail segments, rapid surveys of a large sample of trail segments, and complete censuses of trail problems or conditions.

Replicable Measurement Techniques

Detailed quantitative studies provide an understanding of subtle changes that cannot be detected using rapid survey techniques. If the sampling points are permanently located, change over time can be monitored on these sites, providing particularly valuable information to the manager. Establishing permanent points is worthwhile whenever time-consuming measurements are taken for management purposes, because the additional time invested is usually minor and the benefits of an opportunity for repeat measurements are great.

Two sampling schemes can be used in detailed quantitative studies. First, sampling points can be distributed in either a random or systematic manner along the trail. A systematic scheme, such as locating points every mile along the trail, is more practical. This permits an assessment of the condition of the trail system as a whole. Later remeasurements establish how much change has occurred on this trail during the period it was studied and how that change varies from place to place. However, considerable time may be invested in measuring sites that are of no particular concern to the manager. I have found no published results from studies of this type.

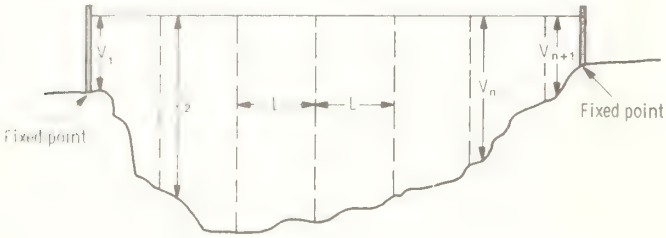
Alternatively, sampling points can be purposively located at places where pronounced change has already occurred or is expected. By concentrating samples on sites of particular concern (for example, sites experiencing pronounced trenching), we can learn much more about change on these particular sites. However, the purposive sampling scheme does not permit an evaluation of changes on the system as a whole. Studies using purposively located samples are relatively common (for example, Ketchledge and Leonard 1970; Helgath 1975; Summer 1980).

The most commonly used method for measuring soil erosion on trails involves measuring the cross-sectional area between tread surface and a taut line stretched between two fixed points on each side of the trail. Periodic remeasurements of these trail transects document the amount of soil lost over the elapsed time.

Leonard and Whitney (1977) provide a detailed description of the technique, using nails in trees as fixed points. As

described, this technique is suitable only for purposive sampling in forested areas. The method can be adapted to treeless areas or to a random or systematic sampling design by using other fixed points, such as rods set in the ground or, preferably, rods temporarily placed, at the time of measurement, in receptacles permanently buried in the ground (Trottier and Scotter 1975). Regardless of what type of fixed point is used, points should be far enough apart to allow for future increases in trail width or the development of multiple trails.

The next step is to stretch a taut line and/or tape measure between the two points. A series of vertical measurements of distance between line and trail tread are taken at fixed intervals along the tape. Precision will be greatest when (1) the line is elevated high enough above the fixed points to clear vegetation and microtopography along the trail, (2) the line is kept taut, and (3) a plumb bob or level is used to take vertical measurements (Coleman 1977). The cross-sectional area below the taut line can then be computed from the vertical measurements using the formula in figure 1.



$$A = \frac{V_1 + 2V_2 + \quad + 2V_n + V_{n+1}}{2} \times L$$

Where A = cross-sectional area

$V_1 - V_{n+1}$ = Vertical distance measurements, starting at V_1, the first fixed point, and ending at V_{n+1}, the last vertical measurement taken.

L = Interval on horizontal taut line

Figure 1.—Layout of trail transect and formula for calculating cross-sectional area.

When remeasurements are taken, the fixed points should be relocated and the taut line should be positioned at precisely the same height above the fixed points as for the original measurements. The vertical measurements should be taken at the same interval and starting from the same side of the trail as in the original measurements. When the cross-sectional area is calculated from these measurements, it can be compared with the original area to determine how much change has occurred and whether soil has been eroded or deposited.

Rinehart and others (1978) developed a technique for measuring cross-sectional area with stereo photographs. After trying both photographic and field measurement techniques, we concluded that field measurements were both more rapid and more accurate.

The location of sampling points must be well documented. Distance from the trailhead can be measured with a highway-distance measuring wheel (cyclometer). If readily visible markers are used, this may be all that is necessary. We have used buried metal stakes as markers to minimize the likelihood of vandalism. We reach the general vicinity of the markers using the cyclometer and photographs taken both up and down the trail from the transect location. The precise location of the markers is noted on a sketch map giving distance and direction to at least three permanent reference points (usually trees recorded by species and diameter at breast height). The metal stakes are found with a metal detector.

Numerous additional measures could be taken at these sample locations. Root and Knapik (1972), Bryan (1977), and Epp (1977), for example, dug soil pits and studied changes in soil profiles. Summer (1980) used a penetrometer to measure compaction, fluorescent pebbles to measure pebble movement, and repetitive photography to measure surface pebble and gravel armoring. However, cross-sectional area is probably the most useful measure for managers in that the technique is replicable, requires relatively little training, and provides results that are easy to use and interpret.

Rapid Survey Techniques

Rapid survey techniques permit more trail segments to be examined, but the only types of observations possible are those that do not take very long. Precision in monitoring is also reduced because sample points are not permanently located. With these techniques, monitoring involves comparing two independent samples, each consisting of a large number of observations, instead of reexamining a single, smaller sample of sites. Despite this reduced precision, the accuracy of trail condition assessments may be greater than with detailed measurements because more trail segments can be examined.

Rapid surveys are most valuable when the primary goal is to evaluate the gross condition of the trail and how it is changing over time. Replicable detailed measures are necessary to detect subtle changes in condition over short periods or to examine more thoroughly the nature of change along trails.

Most rapid surveys have utilized a systematic sampling design and collect data on both trail condition and characteristics of environment, trail design, and use. Samples were taken every 500 ft (152 m) by Root and Knapik (1972), every 164 ft (50 m) by Bayfield and Lloyd (1973), and every 1,640 ft (500 m) by Bratton and others (1979). These studies provide an assessment of overall trail condition, and allow variations in trail condition to be related to differences in site, design, and use characteristics. This leads to a good understanding of where and why trail deterioration is occurring, which can be invaluable when either planning new trails or developing strategies for mitigating existing problems.

If an assessment of overall trail condition is unnecessary, it is more efficient to stratify the sample by site, design, or use characteristics. Summer (1980), for example, made a qualitative assessment of degree of erosion on 60 sections of trail located on contrasting geomorphic surfaces. Stratifying her sample by geomorphic surface allowed her to relate erosion damage to trail location (geomorphic surface) with fewer samples than if she had used a strictly random or systematic sample. This sampling design did not allow her to generalize about overall trail conditions, however.

When using a stratified sampling scheme one must avoid bias when locating samples. Bias can be avoided in at least two ways. Epp (1977) located potential sample sites every 100 paces along the trail. A sample site was used if its environmental characteristics fit into one of the categories in the stratification for which further sampling was required. Alternatively, one could walk along the trail locating segments that fit the desired characteristics and then take the sample at some predetermined distance, such as 20 paces, farther along the trail.

Once a sampling scheme is determined, the choice of what data to collect at each site will depend upon the aims of the study. The most common measures of trail condition have been width of the trail (either the tread or the entire disturbed zone), width of bare ground, and maximum depth of the trail. Bayfield and Lloyd (1973) note the number of parallel trails and the presence or absence of the following "detracting features": rutting, stepping, surface deterioration, gullying, lateral erosion, bad drainage, esthetic intrusions, vandalism, or litter. Summer (1980) used erosion ratings, with written descriptions for each erosion class, to evaluate damage at each sample site. Commonly recorded site characteristics include amount and type of use, vegetation type, slope and aspect of both the trail and the surrounding terrain, landform, parent material, drainage, and soil characteristics.

After these data have been collected, means and standard deviations for each trail condition parameter can be calculated and used to assess the overall condition of the trail. Severely damaged segments can be identified and mapped. Finally, differences in trail condition can be related to environmental, design, and use characteristics using standard statistical techniques. This should help identify likely causes of trail deterioration and means of avoiding future problems.

Census Techniques

Several researchers have censused entire trail systems. Trails are subdivided into individual segments that can simply be described as either damaged or undamaged (Root and Knapik 1972). Some studies have gone a step further and rated the degree of impairment of each segment. Trottier and Scotter (1975) express trail condition in a single number determined by rating five parameters (width, depth, moisture regime, stones and roots on the tread, and walkability). This number is the sum of individual ratings for each of the five parameters. Ratings range from zero (low impact) to three (high impact). Bratton and others (1979) use two rating systems. One is based on quantitative measures of total width; total width minus tread; depth; percent water erosion, mud , rut, horse impact, foot impact, or vehicle track; percent exposed roots or bank erosion; and total area of mud erosion. Their other system has five descriptive classes ranging from the very little erosion class to the very extensive erosion class. The latter class is defined as: "trail to bedrock or other substrate, or tree roots badly damaged, or some ruts more than 50-cm deep, or large areas (over 50%) of bank erosion, or mud holes so extensive that the trail is largely outside of its maintained width" (Bratton and others 1979). Similar rating scales could be adapted to other areas. The key to success is describing each category quantitatively or in prose as precise as possible.

These techniques provide particularly useful assessments of overall trail condition. Although they are more time consuming than taking a sample, complete maps of trail condition can be compiled. Such maps could be very useful to managers for planning and budgeting.

Another useful approach to assessing and mapping trail condition is to census all trail "problems." Again it is important to define precisely what is to be considered a problem. The number and length of problems can be recorded while walking along the trail; then the location of each problem can be mapped. Finally, by noting the site, design, and use characteristics of each problem segment, it is possible to develop a better [illegible] maintenance.

THE CASE OF BIG CREEK TRAIL

To test methods and illustrate how they work, several of [illegible] established trail in the Big Creek drainage of the Selway-Bitterroot Wilderness (fig. 2). Most of the trail system is in [illegible] leave the valley bottoms and nonforested vegetation types are more common. The Big Creek trail is one of the more heavily used trails in the Selway-Bitterroot, by both hikers and stock. The South Fork trail, which branches off from the main trail about 8 miles (13 km) above the trailhead, is infrequently used.

Figure 2.—Location of the Big Creek drainage within the Montana portion of the Selway-Bitterroot Wilderness.

Study Methods

We established 10 permanent trail transects along the main Big Creek trail in 1978. These were systematically located every mile (1.6 km) after establishing a randomly selected starting point. No transects were located on the South Fork trail. In 1979 we established two additional transects across trail segments selected because they were deeply incised.

With all of these transects, a tape was placed flush with the [illegible] trail-side microtopography and, therefore, some precision was lost. [illegible] determined [illegible] sectional [illegible] formula in figure 1. In 1980, the 10 systematically located transects and the two purposively located transects were remeasured.

[illegible] Fork trails, taking observations every 0.2 mile (0.32 km) for a total of 83 observations. At each observation point the following data were collected: overall trail width (the zone obviously disturbed by trampling); bare ground width; maximum depth; presence or absence of multiple trails, trail deepening (maximum depth of over 10 inches [25 cm]), erosion of trail sides, [illegible] areas), and "washboard" (alternating rises and depressions in

the trail caused by horses stepping repeatedly on the same spots); habitat type;[1] and slope, both along and across the trail.

This survey provided data on the overall condition of the trail and the frequency of occurrence of various trail problems. However, the small number of problem observations suggested it would be valuable to look more closely at the problem segments along the trail. Consequently, we censused all trail segments that were either incised more than 10 inches (25 cm) or muddy for at least part of the use season and that were at least 3 ft (0.9 m) long. For each segment we noted length of the problem segment, maximum depth and width of the segment, habitat type, and slope of the trail. We also made observations about soils and landforms, and potential remedies for the problem.

Overall Trail Condition

Results of the systematic sample of trail transects show that between 1978 and 1980, only 4 of the 10 sample sites experienced a net loss of soil; the cross-sectional area below the transect **decreased** on the other 6 sites, indicating that deposition of material exceeded erosion. On those sites with a net loss, the mean loss was 12 in^2 (77 cm^2); losses ranged between 6 in^2 (39 cm^2) and 17 in^2 (110 cm^2). Generally more material was lost from lateral erosion of the "banks" of the trail than from further incision at the deepest part of the trail (fig. 3).

The mean decrease in cross-sectional area on those sites experiencing a decrease was 13 in^2 (84 cm^2), with a range between 1 in^2 (6 cm^2) and 47 in^2 (303 cm^2). The decreases are a result of both slumping of the trail "banks" and infilling of the trail tread (fig. 4). The site where 47 in^2 of material was deposited had been disturbed by trail work immediately upslope.

To test the accuracy of our measurements, 10 replicate measures of one transect were taken. The mean area for the 10 measures was 83.6 in^2 (540 cm^2); the 95 percent confidence limits around this mean were $\pm$ 4.1 in^2 (26 cm^2), about 5 percent of the mean value. The amount of change that occurred in 2 years exceeded this measurement error value on only 5 of the 10 transects. Of these five sites, two experienced a net loss of soil and three a net gain.

These results suggest that over the trail system as a whole little erosion is occurring. Some loss occurs where soil sloughs off banks, is transported by moving water, and deposited where water drains off the trail. However, sediment is also deposited on the trail by overland flow, and material eroded from one trail segment is often deposited elsewhere along the trail. Although individual cross-sectional profiles are changing, the trail as a whole exhibits a relatively steady state. Trottier and Scotter (1975), working in Canada's Banff National Park, also found little short-term increase in the cross-sectional area of trails that were properly located.

A larger sample size would be necessary to draw more definitive conclusions. The rapid survey we took increased the number of observations to 83, although trends over time were not quantified. The mean trail width of the entire trail system was 3.2 ft (98 cm); the mean width of the nonvegetated part of the trail was 2.3 ft (70 cm). The mean maximum depth of the trail was 0.41 ft (12 cm). These values are similar to those recorded elsewhere in the Northern Rocky Mountains (Dale and Weaver 1974), but these trails are narrower and deeper than trails in Great Smoky Mountains National Park (Bratton and others 1979).

The trail problems we defined (multiple trails, deepening, lateral erosion, roots, rocks, mud, and "washboard") were absent on 65 percent of the trail segments we examined. This supports the conclusion of our trail transect study that most of the trail system is in good shape and appears to be stable.

There are, however, certain trail segments with severe problems (fig. 5). Of the 83 segments, 13 percent were more than 5 ft (152 cm) wide; 1 segment was 7.1 ft (216 cm) wide. The width of exposed soil exceeded 4 ft (122 cm) in 8 percent of the cases, and reached 6 ft (183 cm) in one case. Of the segments, 35 percent had at least one problem and 12 percent had more than one problem. Three problems occurred on more than 10 percent of the segments: mud (17 percent); rocks (13 percent); and root exposure (11 percent). Incision of more than 10 inches (25 cm) occurred on 8 percent of the sites, and multiple trails were present at 5 percent. Lateral erosion and "washboard" were rarely encountered.

[1]Habitat types are a site classification system based on potential climax vegetation. We used the types presented in "Preliminary Forest Habitat Types of the Nezperce National Forest" (Robert Steele and others 1976, preliminary draft, USDA Forest Service, Intermountain Station.)

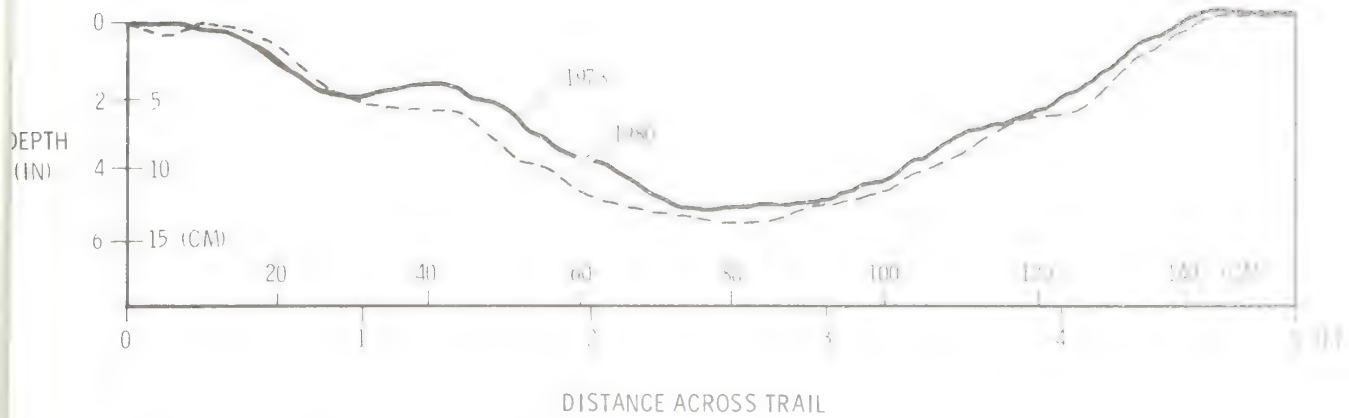


Figure 3.—The cross-sectional profiles for transect 8 indicate a net loss of 17 in^2 (110 cm^2) of material (erosion) between 1978 and 1980.

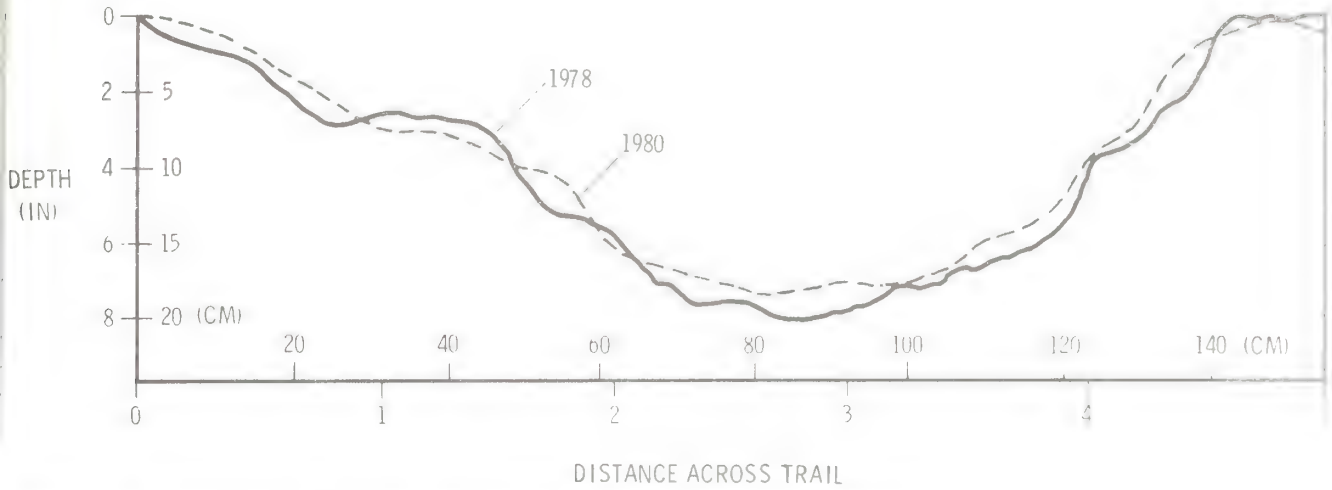


Figure 4.—The cross-sectional profiles for transect 5 indicate a net gain of 15 in^2 (97 cm^2) of material (deposition) between 1978 and 1980.

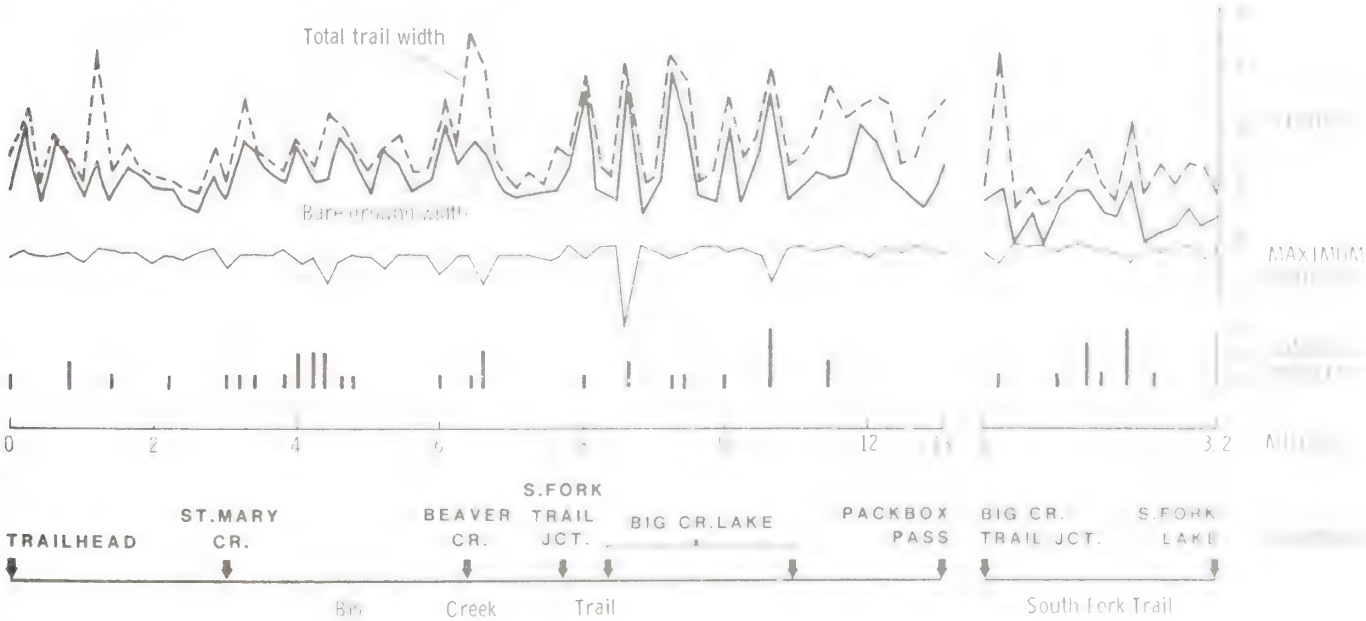


Figure 5.—Measurements and observations taken every 0.2 mile along the Big Creek and South Fork trails.

The severity of trail deterioration in some locations was also illustrated by the results of trail transects at sites purposely selected as examples of deeply incised trails. In 1 year the cross-sectional area at one site (fig. 6) increased 56 in^2 (362 cm^2), from 944 in^2 (6 090 cm^2) to 1,000 in^2 (6 452 cm^2). At the other site, the cross-sectional area increased from 478 in^2 (3 084 cm^2) to 508 in^2 (3 277 cm^2), an erosional loss of 30 in^2 (194 cm^2). These losses occurred primarily as deepening on steep trails and were probably more a result of water erosion than excessive use. The amount of soil loss involved is roughly comparable to that found by Ketchledge and Leonard (1970) in the Adirondacks and by Summer (1980) in Rocky Mountain National Park.

Figure 6.—Deeply incised trail segment on which trail transect measurements showed a 1-year soil loss of 56 in^2 (362 cm^2).

Trail Conditions in Relation to Habitat Type

Using data collected in the rapid survey, we examined the relationship between trail condition and factors related to the trail's location, design, and amount of use. The major locational variable we examined was habitat type. Most of the trail was located in forests with the potential to be dominated by *Abies lasiocarpa*. Three habitat types characterized by *Streptopus amplexifolius, Clintonia uniflora,* or *Menziesia ferruginea* in the undergrowth were common. Two types with a potential overstory of *Abies grandis* and undergrowth characterized by either *Linnaea borealis* or *Clintonia uniflora* were also common. The other types were *Pseudotsuga menziesii/Physocarpus malvaceus* and a nonforested herbaceous vegetation type usually found on avalanche paths.

All measures of trail condition differed significantly between habitat types (table 1). Trail segments located in the *Abies lasiocarpa/Streptopus amplexifolius* type were more consistently in poor condition than segments in other types. Trails in this habitat type, which is indicative of a high water table, are easily trampled into quagmires. Visitors attempting to avoid muddy conditions widen the trail, and water erosion frequently deepens the trail where the water table is intercepted by the trail tread. Working on the west side of the Selway-Bitterroot Wilderness in Idaho, Helgath (1975) found similar problems in *Thuja plicata/Athyrium filix-femina* and *Abies lasiocarpa/Pachistima myrsinites* habitat types. Two of our trail samples were in *Thuja plicata* forest. These samples had three problems each and a mean trail width of 4.0 ft (122 cm), bare width of 3.0 ft (91 cm), and maximum depth of 1.1 ft (34 cm), suggesting that these types are also poor trail locations.

The two *Abies grandis* types had fewer problems. Most problems in the *Abies grandis/Linnaea borealis* type were with exposure of rocks in the trail as finer particles are eroded away. This leads to excessive trail widening as hikers and stock attempt to skirt the rocks exposed in the tread (fig. 7). Excessive muddiness, root, and rock exposure were all occasional problems in the *Abies grandis/Clintonia uniflora* type.

In contrast, trail segments located in nonforested areas were consistently in better shape than segments in other types. The only problem encountered was one case of muddiness where the trail crossed the drainageway of an avalanche slope. These locations are usually better drained than the forests, which have developed on glacial deposits in the valley bottoms. Consequently, trail deepening by water erosion is less pronounced.

Figure 7.—Pronounced trail widening commonly occurs where hikers and stock skirt rough rock outcrops exposed in the trail tread.

Table 1.— Trail conditions in various habitat types[1]

Habitat type	N	Trail width	Bare width	Maximum depth	Problem frequency
		Feet			Percent
Abies lasiocarpa/Streptopus amplexifolius	11	4.9 a	3.2 a	0.66 a	82 a
Abies grandis/Linnaea borealis	9	3.6 b	2.8 ab	.38 ab	55 ab
Abies grandis/Clintonia uniflora	10	2.8 cd	2.1 ab	.39 ab	50 b
Pseudotsuga menziesii/Physocarpus malvaceus	6	2.4 cd	2.3 ab	.48 ab	0 c
Abies lasiocarpa/Clintonia uniflora	15	3.2 bc	2.1 b	.29 bc	20 c
Abies lasiocarpa/Menziesia ferruginea	11	3.2 bc	1.8 b	.28 bc	9 c
Nonforested avalanche slope types	10	2.0 d	.9 c	.18 c	10 c
Mean		3.2	2.3	.41	35

[1]Any two means in a column followed by one or more of the same letters are not significantly different at the 95 percent confidence level, using the difference-of-means and difference-of-proportions tests (Blalock 1972).

Trail Conditions in Relation to Slope

Regressions showed the following significant positive relationship between slope along the trail and maximum depth of the trail:

maximum depth (ft) = 0.30 + 0.02 X (slope in degrees)

There were no significant relationships between slope along the trail and trail width or bare width. The frequency of problems was also unrelated to slope along the trail. Although steep segments often are more highly deteriorated—they are deeper in particular—flat segments are also prone to problems due to poor drainage. Effective use of water bars and other means of controlling erosion can prevent damage on steep trail segments. Even for maximum depth, trail slope does not explain much variability (r^2 = 0.08). It might have if extremely steep pitches were more common and maintenance was less frequent.

Trail Conditions in Relation to Amount of Use

To examine the effects of amount of use, we compared the infrequently traveled South Fork trail with the frequently traveled section of the Big Creek trail above the junction with the South Fork (table 2). The widths of both the entire trail and the bare portion of the trail were significantly greater on the more heavily used trail. The mean maximum depth was greater on the heavily used trail, but the difference was not statistically significant. The relative frequency of problems on the two trails was identical.

Table 2.—Trail conditions in relation to amount of use

Amount of use	N	Trail width[1]	Bare width[1]	Maximum depth	Problem frequency
			Feet		Percent
Light (South Fork)	17	2.4	1.0	0.28	35
Heavy (Big Creek Lake)	[illegible]	3.7	3.0	42	35

[1]Significant at p = 0.05, one-tailed difference-of-mea[illegible]

Other studies support the contention that trail width responds more to amount of use than either trail depth or problem frequency. Bayfield and Lloyd (1973) and Dale and Weaver (1974) both found that trail width increased with increasing use. In a series of experiments, Weaver and Dale (1978) found that a small amount of use caused most of the increase in trail depth they recorded, while trail width continued to increase substantially with further increases in use. A probable explanation is that the major mechanism maintaining a wide trail is trampling. To maintain a bare width of 3 ft (91 cm), a consistently high level of trampling must occur over that area. Where use levels are low, only the central part of the trail—a much narrower path—is trampled frequently enough to remove all vegetation. However, once the vegetation has been removed, even along a narrow path, water erosion can be pronounced. Water erosion is probably the major mechani[illegible] trail deepening in most situations and can be as pronounced on light-use trails as on heavy-use trails. Most problems can also be triggered by low levels of use on a poorly located or poorly maintained trail segment. Beyond this low threshold, further increases in use have little effect on problem frequency. Helgath [illegible] ned and maintained.

[illegible]

[illegible] problems resulting from poor trail location an[illegible] that it made travel difficult, at least seasonally [illegible] to only 1 percent of the trail system, considerably le[illegible] 17 percent of the systematic samples that exhibited [illegible] muddiness problems. The aver[illegible] 43 ft (13 m), but some muddy segments exceeded 100 ft [illegible] than the average of 3.2 ft (98 cm) for the trail [illegible] whole. Trail widening is a frequent consequence of trail muddiness (fig. 8).

Figure 8.—This muddy trail segment is more than 6 ft (183 cm) wide and provides a good example of multiple trailing and "washboard."

[illegible] *Abies lasiocarpa*, *Streptopus amplexifoli*[illegible] systematic sample indicated that only about 1[illegible] *filix-femina*, *Boykinia major*, *Senecio triangularis*, or *Veratrum viride* was usually a strong indicator [illegible] lems. These same species have also been identified as reliable indicators of unstable slopes (Pole and Satterlund 1978). Most [illegible] as a guide when locating trails (Proudman [illegible]

About one-third of the problems on [illegible] relocated completely out [illegible] duroy, or turnpikes. Most trail assessmen[illegible] that improvin[illegible] most effective solutions where rerouting is not feasible (Root and Knapik 1972; Ba[illegible]

We found that 45 segments, about 2,500 ft (762 m), were deeply incised. The average length of these segments was 57 ft (17 m); the average depth was 1.6 ft (48 cm). The average width was 2.2 ft (67 cm), less than the average for the trail system as a whole.

Incision problems occurred on a wide variety of habitat types, so we could not identify any useful vegetative indicators of potential problems. Almost 90 percent of the problems occurred where the slope along the trail exceeded the overall trail average of 4.7 degrees (fig. 9). The mean slope for problem trail segments was 11.5 degrees (more than a 20 percent slope). About 80 percent of the problems could be solved either through better use of water bars or by ditching trails so that drainages are not diverted down the trail. However, most of these segments are so deeply eroded that they would have to be filled in before water bars could be effective. This emphasizes the importance of recognizing the need for such drainage devices during initial trail construction.

Figure 9.—Trail incision commonly occurs even on moderate slopes if water bars have not been used.

Erosion on gentle slopes usually occurred in soils with uniform textures, particularly in the fine sand to silt size classes. These are most likely small areas of outwash or lacustrine deposits in a matrix of glacial till. Root and Knapik (1972), working in the Canadian Rockies, also found such locations to be particularly erosive. Localized trail rerouting through till deposits would alleviate most of these problems.

MANAGEMENT IMPLICATIONS

Value of the Techniques as Management Tools

These techniques provide two types of information that can be useful to the manager. First, they can provide guidelines for trail location, relocation, design, and maintenance. Both rapid survey and census techniques can be used to gather information. We feel the best method is to take a census of problem trail segments, look for associations between problems and environmental conditions (such as habitat type, slope, or parent material), and suggest solutions to the problems. This amounts to learning from past mistakes. Not all trails need to be examined. Choose trails that are examples of the range of conditions in the area of concern, develop guidelines for these conditions, and extrapolate the results elsewhere. Indicators of potential trail problems should be identified and trail design features should be developed to avoid problems where poor locations cannot be bypassed.

These surveys should be taken by personnel well trained in ecology and soil science, preferably with experience in trail construction and maintenance. While such a survey involves an initial outlay of funds, this investment will be quickly recovered in reduced trail relocation, maintenance, and rehabilitation costs. This is probably the most useful type of trail analysis the manager can undertake.

Managers should also be concerned about monitoring trail conditions to determine the effectiveness of their trail management programs. The first step in developing a monitoring program is to decide which types of trail deterioration are of most concern, and whether to monitor the severity of individual problems (for example, how wide the trail is), the frequency of problems (for example, the number or length of excessively wide trail segments), or both.

These decisions should be in written standards stating conditions that are unacceptable. Standards might state, for example, that no trail segment should be deeper than 1 ft, that muddy segments should be no longer than 10 ft, or that no more than 1 percent of the trail should be more than 3 ft wide. Once standards have been defined, trails can be surveyed to determine whether current conditions are acceptable or not. If they are not, mitigating actions will be necessary. Periodic reassessments will show whether these actions are successfully controlling the problem.

Rapid survey assessments noting presence or absence of problems or simply measuring trail width or depth should usually be sufficient for monitoring overall trail condition. A census of all segments with potential problems will be necessary where a standard has been written to limit the severity of individual problems. For example, if a standard states that no trail segment will be deeper than 1 ft, monitoring should involve periodically measuring the depth of all segments where depth might exceed 1 ft. Systematic sampling, however, can provide a more efficient estimate of problem frequency. If the standard stated no more than 1 percent of the trail will be deeper than 1 ft, depth measurements could be taken every 0.2 mile (or some other distance) to see if depth exceeds 1 ft on more than 1 percent of the sample segments.

More detailed monitoring of permanent sites would be useful to managers wanting to evaluate how well some trail hardening or maintenance technique is working. Changes over time could be followed on otherwise similar hardened and nonhardened trail segments to determine the effectiveness of the hardening technique. Such a study would also be useful in evaluating the consequences of a change in amount or type of use. Detailed monitoring of randomly or systematically located sites will be of limited use to managers.

Trail Management

A major conclusion of these studies is that most of the Big Creek trail system is in good condition. Erosional loss from the trail is generally low, and problems are absent on most of the trail. The severely deteriorated segments we surveyed amounted to only 4 percent of the trail system. Similar conclusions have also been reached for most other trail systems examined (for example, Root and Knapik 1972; Bayfield and Lloyd 1973).

These results suggest that the significance of trail deterioration to maintaining natural conditions in the Big Creek area and elsewhere is negligible. The only important ecological effect

likely to occur would be if the trail disturbed an extremely rare plant, animal, or ecosystem. It is unlikely that this has happened in the Big Creek drainage. Where this does occur, the problem is a result of trail placement, not trail deterioration, and the solution is relocation.

Managers, however, should not interpret this to mean they can be lax in minimizing ecological disturbance associated with trails. Rather it suggests that in most cases the significance of trail deterioration problems should be determined primarily by their effect on the visitor's experience. Lee (1975) found that backcountry visitors were bothered most by features that detract from the trail's functional ability to provide a pleasant and easy walking surface, such as loose rock or muddiness. As long as trails are not unnecessarily overengineered, trail characteristics that are primarily esthetic detractions, such as excessive trail width, are probably less important, although they certainly can be bothersome to some people. Therefore, in a monitoring program, managers might want to pay particular attention to changes that make a trail more difficult to walk along.

Although trail condition is generally good, some trail segments have severe problems. The probability that a given segment will deteriorate is a function of the trail's immediate environment, its design and maintenance, and the amount and type of use the trail receives. In the Big Creek drainage, amount of use had a significant effect on trail width and bare width, features probably of secondary importance to visitors and in terms of ecological impact. The slope of the trail affected only the maximum depth of the trail. Deeply incised trail segments are a significant impact. However, until incisions become so deep that footing is difficult, they are probably a less severe problem in the eyes of the visitor than is muddiness. Frequency of muddiness and other trail problems, as well as trail width, bare width, and maximum depth, all differed between habitat types, indicating that the most significant trail problems are primarily related to local environmental conditions. This conclusion is supported by the results of several other studies that found that more variability in trail conditions is explained by local environment (usually vegetation type) than any other factor (Bayfield and Lloyd 1973; Helgath 1975; Weaver and others 1979).

Such a conclusion implies that most problems can be avoided through careful attention to trail location. In the Big Creek drainage, trail problems would have been minimal if the route had avoided areas with a high water table, often indicated by the *Abies lasiocarpa/Streptopus amplexifolius* habitat type, and glacial deposits with a homogeneous silt to fine sand texture. Where these locations cannot be avoided, problems could be reduced through proper design during construction. Areas with a high water table need to be either drained or bridged (Proudman 1977). In the glacial deposits, slopes should be minimal and water bars should be used and frequently maintained. Proper trail location avoids most problems, while engineering avoids most remaining problems. Restrictions on amount of use are less helpful.

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Cole, David N. Assessing and Monitoring Backcountry Trail Conditions. Res. Pap. INT-303. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 10 p.

Three types of trail assessment techniques—replicable measurements, rapid surveys, and censuses—can provide useful information for backcountry managers. This paper discusses how to apply these methods in the field and utilize the results to improve backcountry management. To illustrate their application, specific techniques are applied to the Big Creek trail system in the Selway-Bitterroot Wilderness.

KEYWORDS: monitoring, wilderness, backcountry management, trails, ecological impact, trail condition

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Paper
INT-304

February 1983

Problems and Practices in Wilderness Management: A Survey of Managers

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RESEARCH SUMMARY

This report presents the results of a survey of the managers of all units within the National Wilderness Preservation System and many units that will probably be added. Use characteristics, management problems, management techniques, nonconforming uses, and other topics of interest are described for 269 areas. Information is most frequently organized by administering agency, but also by status of the area (wilderness, proposed wilderness, or primitive area), and by region of the country. Important differences in agency philosophy are highlighted. A tabular summary of key data provides opportunities for detailed analysis and further study, and also documents current conditions for future comparison.

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Problems and Practices in Wilderness Management: A Survey of Managers

Randel F. Washburne
David N. Cole

INTRODUCTION

The National Wilderness Preservation System (NWPS), encompassing almost 80 millon acres in 1980 and spanning over 6,000 miles, is a tremendously varied system. It includes areas that are virtually unvisited, as well as areas that receive enormous pressures from nearby urban populations. It includes tundra, desert, forest, and swamp. Within the unifying legislated purpose of wilderness set forth in the Wilderness Act of 1964, each of the four agencies that manage the NWPS, the Forest Service (FS), National Park Service (NPS), Fish and Wildlife Service (FWS), and Bureau of Land Management (BLM), imposes its own mandates and policies on wilderness. The result is a decentralized mosaic of physical and management situations loosely united through the general and sometimes contradictory provisions of the Wilderness Act.

At this time, no areas managed by the BLM have been designated wilderness. The BLM primitive areas, however, are likely to be added to the NWPS, and three parcels of BLM land adjacent to FS wilderness are managed by the FS.

Given this tremendous diversity, we felt it would be worthwhile to survey the problems and practices of the areas that comprise the NWPS. Such a survey would be a valuable reference—now and in the future—on wilderness conditions and management in 1980. Two previous surveys of wilderness practices omitted many component areas in one case (Godin and Leonard 1979) and did not include a number of topics that we considered to be important (Bury and Fish 1980, Fish and Bury 1981).

A survey of the NWPS could be useful to wilderness managers and planners and to the research community. Managers could gain insight from an improved perspective on how their area's unique problems and practices relate to those of other areas. Planners, whether at the national, regional, or local level, could profit from an overview of the distribution and severity of problems and the various responses that managers are taking to these problems. Researchers could find potential study areas with conditions that were appropriate for their research needs. In the future, it would be possible to determine how wilderness problems and practices have changed by comparing these results to reassessments of the situation.

SURVEY METHODS

Questionnaires were sent to the managers of all NWPS units in the system in 1980. (Sample questionnaire is available from the Wilderness Management Research Unit, Forestry Sciences Laboratory, Missoula, MT 59806.) Areas likely to be added to the NWPS in the next few years were included. Therefore we also surveyed primitive areas administered by the FS and BLM, and areas administered by the NPS and FWS for which wilderness proposals were currently before Congress. Other potential additions, such as RARE II areas and many areas that have been designated since the survey in 1980, were not included.

For the FS units, each forest managing a portion of the area received a questionnaire. Thus 40 FS units are represented by two or more questionnaires. This was done because use data and other statistics are often collected at the forest level and because problems and management responses also vary between forests. This inflation of the number of FS units should be kept in mind. The 308 units included in this survey represent 269 wilderness, proposed wilderness, or primitive area units.

We obtained some data from all 269 areas surveyed. However, for several of the FS areas we did not receive questionnaires from all managing forests, and for one NPS area we only obtained selected information over the telephone. Nevertheless, answering the questionnaire required a considerable amount of data compilation and thought; the commitment of the managers to this survey is appreciated. Many of our questions asked for managers' perceptions; such perceptions may vary between managers in any given area.

This report is a compendium of the broad range of topics included in the survey. Results are mainly reported in tabular form, with brief discussion. Generally, cross tabulations were confined to major variables of interest including the agency administering the area, status of the area (wilderness, proposed wilderness, or primitive area), and region. Regional boundaries are shown in figure 2 in the appendix (p.17).

Appendix A includes a tabular summary, by area, of the survey. The summary shows which areas responded similarly to each question. Thus it is possible to identify all areas that ration use, report problems with wildlife, and so forth. One can also examine all data for any area of particular interest. The units are organized by agency, status, and within these categories by region. Though somewhat cumbersome, the summary presents current conditions within the system and provides an opportunity for further analyses.

USE CHARACTERISTICS

Though the National Wilderness Preservation System was founded to serve a variety of purposes (preservation of natural ecosystems, scientific and research values, esthetic values, and others), recreation provides, if not the most important, at least the most evident and easily measured "output." One purpose of this study was to assess the extent and character of recreational use and problems it may have created.

Because use-measurement units differed (12-hour visitor-days, visits, overnight stays, and miscellaneous other units), all measures were roughly converted to visitor-days by means of the following formulas:

(a) **visits**

$$RVD = (V - VD)\,2L + 0.3\,VD$$

(b) **overnight stays**

$$RVD = 2\,N + 0.3\,(N/L)[D/(1\text{-}D)]$$

where:

RVD = number of 12-hour visitor-days
V = number of visits
D = decimal proportion of visits that is day-use
L = average length of stay for campers in nights
N = number of overnight stays

The units surveyed total more than 45 million acres and received almost 12 million visitor-days of recreational use (table 1). Since the survey, acreage in the NWPS has increased to almost 80 million acres, largely through the addition of lands in Alaska. This use is not evenly distributed. Designated wilderness comprises about 42 percent of the acreage, but receives 76 percent of the use (table 2). Proposed areas are underrepresented in use, and primitive areas are proportionately represented. Similarly, FS units comprise 39 percent of the acreage, but receive 71 percent of the use; NPS, FWS, and BLM units are underrepresented.

Table 1.—Status of the National Wilderness Preservation System and likely additions in 1978

Area status	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	Total
	Number of areas Thousands of acres[1] Thousands of visitor-days[2]				
Wilderness	142 15,067 7,839	25 3,016 1,067	52 773 150	0 0 0	219 18,856 9,056
Proposed wilderness	0 0 0	24 16,439 1,998	33 7,154 129	0 0 0	57 23,593 2,127
Primitive area	21 2,630 653	0 0 0	0 0 0	11 234 51	32 2,864 704
Total	163 17,697 8,492	49 19,455 3,065	85 7,927 279	11 234 51	308 45,313 11,887

[1]Acres for most areas were rounded to the nearest thousand; areas less than 1,000 acres were rounded to the nearest 10

[2]Because NPS reported use for some units in visits or overnight stays, these were converted to 12-hour visitor-days, using the proportion of users that are day-users, the length of stay for overnight-users, and presuming that day-use visits are 0.3 visitor-day in duration.

Table 2.—Comparison of recreational use and acreage

Area status	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	Total
	Percents of: total acres total visitor-days				
Wilderness	33.3 65.9	6.7 8.9	1.7 1.2	0 0	41.6 76.1
Proposed wilderness	0 0	36.3 16.8	15.8 1.0	0 0	52.1 17.9
Primitive areas	5.8 5.5	0 0	0 0	0.5 .4	6.3 5.9
Total	39.1 71.4	42.9 25.8	17.5 2.3	0.5 .4	100.0 100.0

Because this study's main concern is with management of recreational use, FWS units receiving little or no use will not be considered further. Only 29 of the 85 refuges studied have more than 500 visitor-days of use per year. These 29 will be the only FWS units included in the rest of this report.

Use by area is unevenly distributed. Figure 1 shows that 80 percent of the visitor-days occur in units that comprise only 20 percent of the total acreage. Furthermore, use within areas is also highly concentrated (Hendee and others 1978), although we did not deal with this topic in the questionnaire.

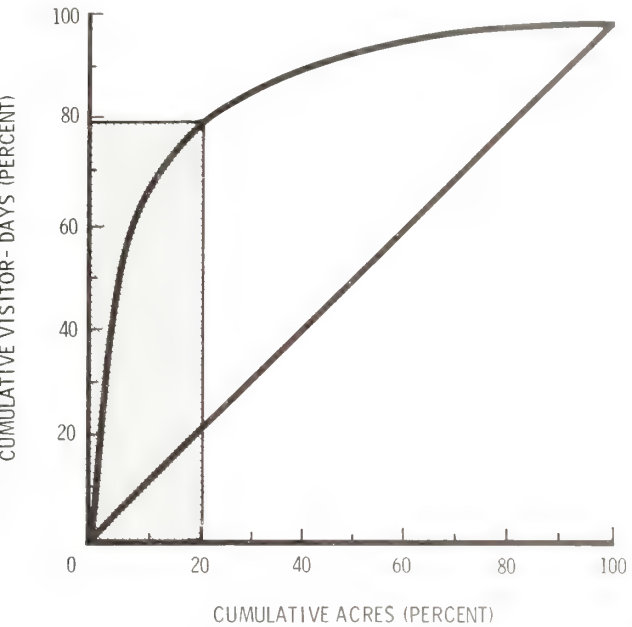

Figure 1.—Recreational use concentration in the National Wilderness Preservation System.

Use distribution through the year is also uneven. For the nation as a whole, more than 50 percent of the use occurs during summer (June through August). Forest Service units generally receive a larger proportion of their use in the summer and fall months than areas administered by the other agencies. As would be expected, seasonal use patterns vary between different regions of the country and, for every month of the year, there are some units that receive at least 10 percent of their annual use during that month.

Table 3 compares per-acre and per-trail-mile use densities in areas administered by the different agencies and in different statuses. Per-acre densities are highest in FS units, particularly in designated wilderness, and are lowest in FWS units and areas of proposed wilderness. Per-trail-mile densities are highest in FWS units and in designated wilderness; they are lowest in BLM units and primitive areas.

These contrasting interpretations of use density result from pronounced differences in the degree of trail development. Forest Service units are heavily trailed; they comprise 39 percent of the acres, but contain 72 percent of the total trail miles. In contrast, FWS units have 17 percent of the acres, but only 2 percent of the trail miles. National Park Service units have 43 percent of the acres and 25 percent of the trail miles. Although the use of NPS and FWS units is less dense than that occurring in FS units, it is spread over a much smaller trail net. This would suggest that the potential for crowding on trails is greatest in the FWS and, to a lesser extent, the NPS units.

Table 3.—Use densities by acre and mile of trail

	Visitor-days per acre per year Visitor-days per mile of trail per year				
Status	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	Total
Wilderness	0.52 434	0.35 825	0.19 1,086	— —	0.48 464
Proposed wilderness	— —	0.12 324	0.02 341	— —	0.09 326
Primitive areas	0.25 185	— —	— —	0.22 97	0.25 174
Total	0.48 394	0.16 411	0.04 541	0.22 97	0.26 395

For the NWPS as a whole, almost one-half of the parties are day-users, and the average length of stay for camping parties is 3.0 days (table 4). National Park Service and FWS units differ from FS and BLM areas by having a greater proportion of day-use and a shorter length of stay for those that do stay overnight in the wilderness or backcountry. Higher day-use and shorter stays also contrast the East from the West.

Eleven percent of the parties using the NWPS take packstock. Use of packstock is highly concentrated in FS and BLM units in the Rocky Mountain and Pacific States.

Outdoor education programs, such as Outward Bound and the National Outdoor Leadership School, contribute a relatively minor portion of use, though in Hawaii and Alaska these groups comprise 8 percent of the parties.

The use of outfitters and guides is also fairly minor for the system as a whole, and is almost nonexistent in the refuges. Outfitter use is most prevalent in BLM and FS units, particularly in the Rocky Mountain States.

Hunters make up a significant group (17 percent of all parties), except in the National Park units where hunting is generally prohibited. Over one-quarter of the parties in units in the Midwest and Alaska are hunters.

Table 4.—Use composition in the National Wilderness Preservation System

Agency and region	Average of parties that are day-users	Average length of stay for camping parties	Average of parties using stock	Average of parties associated with Outward Bound or similar organizations	Average of parties using guides or outfitters	Average of parties that are hunters
	Percent	*Days*	*Percent*			
Agency						
Forest Service	37	3.2	15	3	8	17
National Park Service	62	2.5	3	3	5	0
Fish and Wildlife Service[1]	83	2.8	1	2	1	20
Bureau of Land Management	44	3.2	20	3	11	22
Region						
Northeast	63	2.2	0	2	0	24
Midwest	71	2.5	1	4	1	27
Southeast	75	2.3	3	1	3	14
Rocky Mountain	45	3.0	18	3	9	20
Pacific	35	3.2	8	2	5	11
Alaska and Hawaii	37	4.9	3	8	4	31
All units	47	3.0	11	3	7	17

[1]Includes only refuges with more than 500 visitor-days of use per year

SOCIAL IMPACTS

Crowding, at least as perceived by managers, is a problem confronting less than half of the areas, and only 10 percent of the area managers see it as a problem in many places (table 5). Crowding problems appear to be most common and severe in FS units where per-acre densities are highest. Managers of wilderness also report more problems with crowding than managers of proposed or primitive areas. Regionally, crowding appears to be most prevalent in the Northeast.

Table 5.—Crowding of recreation use as a problem (246 areas responding)

Item	Crowding seen as: Not a problem	A problem a few places	A problem many places
	Percent of areas		
Agency			
Forest Service	45	42	13
National Park Service	63	35	2
Fish and Wildlife Service	73	19	8
Bureau of Land Management	72	27	0
Area status			
Wilderness	51	38	11
Proposed wilderness	63	31	6
Primitive area	59	34	6
Region			
Northeast	38	38	25
Midwest	67	33	0
Southeast	60	40	0
Rocky Mountain	56	32	12
Pacific	44	45	11
Alaska and Hawaii	63	37	0
All areas	53	37	10

A second problem is conflicts between different types of recreational users, such as between hikers and horse users, or river rafters and jet boaters. Only 29 percent of the areas report a problem, and problems are widespread in only 2 percent of the areas. Problems are more common in FS units than elsewhere.

Finally, managers were asked about two types of law violations: (1) trailhead vandalism and theft from cars and (2) theft of food or equipment within the area. Thefts occurring within the area are quite rare; only 3 percent of the areas report this as a problem. Trailhead break-ins, however, are a problem in 27 percent of the areas. They are most prevalent in FS and NPS areas and in the Northeast, Midwest, and the Pacific States, especially California, where 38 percent of the areas have experienced theft and vandalism.

BIOPHYSICAL IMPACTS

Recreational impacts on the biophysical resources of wilderness are a worrisome problem to managers charged with the responsibility of maintaining natural conditions. Problems include changes in vegetation and soil characteristics, wildlife impacts, water pollution, litter, and improperly disposed of human wastes. Managers were asked if each of these types of impact was a problem and, if so, whether the problem occurred in a few or in many places. For vegetation and soil changes, we differentiated those caused by humans from those caused by packstock and compared the frequency of problems along trails with problems in campsites and along lakeshores. Wildlife impacts are arranged by type of animal, but we did not distinguish between areas with highly localized problems and areas with widespread problems.

Vegetation changes caused by human use are common, particularly on campsites, where 71 percent of the area managers

eport problems (table 6). Impacts around lakeshores are also requent. Vegetation change is much less prevalent along trails han elsewhere, but is at least a localized problem in 44 percent of the areas. Interestingly, problems with vegetation impacts re more common and widespread than the crowding problems liscussed previously.

Table 6.—Human impacts on vegetation

Location	Percent of areas that see this as: Not a problem	A problem a few places	A problem many places	Number responding
Trails	56	35	9	234
Campsites	29	44	27	228
Lakeshores	40	42	18	218

Percent of areas having "a problem in many places" at either trail, campsite, or lakeshore locations

Agency		Region	
Forest Service	34	Northeast	25
National Park Service	27	Midwest	7
Fish and Wildlife Service	7	Southeast	20
Bureau of Land Management	18	Rocky Mountain	30
		Pacific	38
		Alaska and Hawaii	11

Managers of over one-quarter of the areas in the FS and NPS consider human impacts on vegetation to be a problem in many places. Vegetation impacts do not appear to be a problem in areas administered by the FWS. Problems are equally common in designated wilderness, proposed wilderness, and primitive areas. In terms of regional distribution, they are most common in the Pacific and Rocky Mountain States, and least common in the Midwest.

Results of human impact on soil, such as erosion, compaction, and bog formation, are also considered a problem in a majority of areas. On campsites and along lakeshores, they are a slightly less common problem than vegetation impacts. On trails, however, they are much more common and widespread, occurring in 61 percent of the areas. Human impacts on soil are most pronounced in the Northeast.

Packstock impacts on vegetation are relatively minor (table 7). Where they are a problem, the problems are usually localized. On the other hand, one should keep in mind that 25 percent of the areas have no packstock use and, therefore, no problems. Moreover, use by parties with packstock comprises only 11 percent of the average area's use. As with human impact problems, packstock-caused vegetation change is most pronounced on campsites.

Packstock impacts on vegetation are most pronounced in FS areas and are virtually absent outside of the Pacific and Rocky Mountain States. This holds true for packstock impacts on soil as well.

Table 7.—Packstock impacts on vegetation

Location	Percent of areas that see this as: Not a problem	A problem a few places	A problem many places	Number responding
Trails	71	24	5	211
Campsites	55	34	11	207
Lakeshores	68	28	4	190

Percent of areas having "a problem in many places" at either trail, campsite, or lakeshore locations

Agency		Region	
Forest Service	12	Northeast	0
National Park Service	4	Midwest	0
Fish and Wildlife Service	0	Southeast	0
Bureau of Land Management	0	Rocky Mountain	14
		Pacific	14
		Alaska and Hawaii	0

Little research has been conducted on the impact of recreation on wildlife (Ream 1980), but this is considered a problem in some areas (table 8). Perceived effects on large nonpredatory mammals and birds are most common. Such effects are generally most common in the NPS areas, although impacts on birds occur frequently in FWS areas and impacts on large mammals are common in BLM areas. Regionally, only the Midwest has few wildlife impact problems.

Water pollution is considered to be a problem in only 18 percent of the areas; it is a widespread problem in only 2 percent of the areas. It is more commonly considered to be a problem in FS areas than in areas administered by other agencies, and is also more frequently a problem in designated wilderness than in proposed areas. It is most prevalent in the Pacific region. Most research to date suggests that recreation-caused pollution of wilderness waters currently poses little threat to health.

Problems with litter, in contrast to pollution, occur in 62 percent of the areas (table 9). Only 12 percent of the areas report that it is a problem in many places, however. Litter appears to be a more troublesome problem in FS areas than in areas administered by other agencies.

Improper disposal of human feces is a problem in 46 percent of the areas, but is generally not a problem in many places within individual areas. The FS appears to have more problems than other agencies. The feces problem is also more prevalent in western areas than in eastern areas.

Finally, we asked managers to describe their most significant problem. The problem mentioned most often was local resource degradation and lack of solitude as a result of concentrated use. Illegal use of the wilderness, particularly use of motor vehicles, but also illegal grazing of livestock and illegal outfitters, was also frequently mentioned. All other problems were mentioned much less commonly. Problems mentioned by five or more managers include poor camping practices, litter, livestock grazing, mineral claims, wildlife conflicts, and problems with hunters and outfitters. A wide variety of administrative problems, including lack of funding, were also mentioned.

Table 8.—Recreational impacts on wildlife

Agency and region	Percent of areas indicating impacts on the following types of wildlife are a problem:							
	Fish	Reptiles	Birds	Small mammals	Large mammals	Predatory mammals	Marine mammals	Other
Agency								
Forest Service	6	1	4	2	20	4	0	2
National Park Service	4	0	29	8	31	22	4	6
Fish and Wildlife Service	0	0	45	0	14	0	0	3
Bureau of Land Management	9	0	9	0	36	9	0	0
Region								
Northeast	0	0	38	0	25	0	0	13
Midwest	0	0	3	0	7	7	0	0
Southeast	3	0	37	0	3	17	3	0
Rocky Mountain	6	0	8	1	33	5	0	3
Pacific	4	1	14	7	14	7	0	1
Alaska and Hawaii	11	0	0	11	22	22	11	11
All areas	5	1	13	3	22	8	1	3

Table 9.—Problems with litter (246 areas reporting)

Agency and region	Percent of areas that see this as:		
	Not a problem	A problem a few places	A problem many places
Agency			
Forest Service	31	55	14
National Park Service	48	39	13
Fish and Wildlife Service	52	41	7
Bureau of Land Management	54	46	0
Region			
Northeast	25	75	0
Midwest	54	39	8
Southeast	33	47	20
Rocky Mountain	41	46	13
Pacific	31	58	11
Alaska and Hawaii	50	50	0
All areas	38	50	12

CARRYING CAPACITY EVALUATION

Carrying capacity is not a new concern in wilderness or backcountry management, but there is increased need to come to grips with this complex problem in a way that can be applied objectively to planning and management. In 1980, the Forest Service's regulations for applying the National Forest Management Act specifies that wilderness plans will:

> Provide for limiting and distributing visitor use of specific portions in accord with periodic estimates of the maximum levels of use that allow natural processes to operate freely and that do not impair the values for which wilderness areas were created (U.S. Federal Register 1979).

Though this mandate applies only to FS wilderness, wilderness and undesignated backcountry in the other agencies are also facing pressures to resolve the question of how much use is appropriate. We asked managers how far they have gone in determining capacities for their area.

It is significant that almost half of the areas have not begun to come to grips with the question of carrying capacity (table 10). The NPS has made the most progress; 21 percent of the areas have established limits in all travel zones. All other agencies have a considerable amount of work yet to be done on this issue.

Table 10.—Progress in assessing carrying capacity (250 areas responding)

Status of capacity assessment	Percent of areas				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Carrying capacity limits have been established for each travel zone (or similar subunit and/or for the whole area).	9	21	10	9	12
Carrying capacity limits have been established for **some** travel zones (or similar subunits), but not for others.	6	7	3	0	5
Though no formal limits have been established, approximate capacity limits are **estimated** for the more heavily used parts of the wilderness.	39	36	35	9	37
We are presently unable to estimate capacity for any portions of the wilderness.	46	36	52	82	46
Total	100	100	100	100	100

Recognizing that often capacity is a matter of opinion, managers of all areas were asked how current use fits the area's capacity. Few areas (2 percent) are overused throughout (table 11). The FS areas appear to have the most chronic capacity problems, although these are localized. Chronic "overuse" is less frequent in NPS areas; in fact, "overuse" would seldom occur even if use was not controlled. This is a surprising conclusion because many National Parks restrict use. (See section on management techniques.) FWS and BLM areas have the fewest capacity problems; more than half of each group have no "overuse."

Table 11.—Relationship of use to carrying capacity (assigned or estimated) (249 areas responding)

	Percent of areas				
Capacity-use relationship	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Use does not exceed capacity in any part of this area.	27	30	59	64	33
Use **sometimes** exceeds (or would exceed without controls) capacity in some localized portions of this area	35	53	31	27	38
Use **usually** (more than a few times during the use season) exceeds capacity in some localized portions, but other parts of the area are underused	35	17	7	9	27
Use usually exceeds capacity for **most** parts of this area	3	0	3	0	2
Total	100	100	100	100	100

For those areas with capacity problems, managers were asked to compare the number of times that resource "damage" was the limiting factor to the number of times that crowding limited capacity. Both factors were important, but an average of 53 percent of the problems were attributed to crowding. The situation varies, however. The seven NPS areas reporting capacity problems attributed an average of 75 percent of the problems to resource damage.

The managers with "overuse" problems were also asked about the kinds of redistribution or curtailment schemes that would bring use within capacity. Most areas with use problems (83 percent) are able to compensate through use redistribution; more than two-thirds indicated that either local redistribution or redistribution to other travel zones, while still leaving some zones with little or no use, would alleviate their overcapacity problems (table 12).

Managers were asked, "Using management techniques allowed by policy, do you think it would be possible to increase the amount of use that your wilderness as a whole receives and still meet your management objectives for wilderness?" Eighty-six percent of the managers responded that they could increase use by an average of 87 percent. All 11 BLM areas could receive more use (135 percent more). In comparison to FS and FWS areas, more NPS areas could increase use (90 percent), and the average increase could be greater (104 percent). This is consistent with the parks' tendency to have less difficulty with use exceeding capacity (table 11), but is contrasted to their propensity to ration use and regulate camping more highly than other agencies.

Table 12.—Solutions to overuse problems, including responses of some managers without overuse problems

	Number of areas (percent)				
Overuse solution	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Heavily used zones could be (or are) kept within their "capacity" by dispersing or controlling use more effectively **locally** (such as around [illegible] within lake basin). Total use of the wilderness is not reduced	8 (12)	2 (20)	1 --	0 --	11 (14)
Areas in the wilderness could be (or are) kept within their "capacity" by redistributing use from overused zones to underused zones (such as lake basins, etc.), while still leaving some zones with little or no use in the wilderness. Total use of the wilderness is not reduced	35 (56)	5 (50)	1 --	1 --	42 (55)
Areas could be (or are) kept within their "capacity" by distributing use relatively evenly throughout the various zones of the wilderness (resulting in all zones at or near "capacity"). Total use of the wilderness is not reduced	11 (17)	0 0	0 -	0	11 (14)
Redistribution of use to other zones within the wilderness cannot keep areas within their "capacity," unless use of the wilderness as a whole is limited. Total use of the wilderness is reduced	9 (14)	3 (30)	1 --	0 --	13 (17)
Total	63 (100)	10 (100)	3 --	1 --	77 (100)

MANAGEMENT TECHNIQUES

Managers have developed many techniques for avoiding or mitigating resource impact problems and maintaining high-quality user experiences. For discussion purposes, these techniques have been placed in one of four categories, according to the intended purpose of the technique. First, managers can require permits, ration use, or limit length of stay in order to place a limit on total use. Second, they can attempt to alter the distribution of visitors by providing information intended to encourage use dispersal or by improving or impeding access. A third strategy is to influence user behavior and to restrict certain types of use—limiting party size, restricting packstock and camping, and initiating a minimum impact educational program. Finally, the physical resource itself can be manipulated through site closures, which may or may not involve assisted revegetation, a program to eliminate campfire rings, and, in some cases, site hardening.

Limiting Use

Most areas (80 percent) do not ration use and do not plan to do so in the next few years (table 13). Where use rationing has been instituted, it usually applies only to overnight-users; day-use is seldom restricted. Five areas ration just one type of use, usually river floating.

The NPS rations use much more frequently than any of the other agencies, although the BLM is planning to start rationing use in a number of primitive areas in the next few years. Apparently the decision to ration use reflects agency policy more than the extent to which use exceeds carrying capacity. Although use of FS areas exceeds capacity more often than use of NPS areas (table 11), the NPS is more likely to institute rationing. There are no pronounced regional differences in the number of areas that ration use.

Of the areas that ration or are planning to ration use, most issue permits for campsites or travel zones (table 14). Few areas allow unrestricted use of a wilderness after a permit is obtained, although quite a few areas allow unrestricted travel once a trailhead is selected. The NPS is most likely to issue permits for campsites, requiring visitors to have prepared an itinerary prior to entry.

Table 13.—Use rationing

Agency	Ration all use	Ration just overnight use	Ration specific users (e.g., floaters)	Plan rationing in next few years	Have no plans to ration
	Number (percent) of areas that:				
Forest Service	3 (2)	7 (4)	4 (3)	7 (4)	142 (87)
National Park Service	1 (2)	17 (36)	1 (2)	3 (6)	25 (53)
Fish and Wildlife Service	1 (4)	1 (4)	0 (0)	1 (4)	24 (89)
Bureau of Land Management	1 (9)	0 (0)	0 (0)	2 (18)	8 (73)
All agencies	6 (3)	25 (10)	5 (2)	13 (5)	199 (80)

Table 14.—Location for which rationed permits are issued

Permits required for	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
	Number of areas				
Campsite	4	12	1	0	17
Travel zone	8	9	1	0	18
Trailhead	5	3	2	1	11
Whole wilderness	2	1	1	1	5

Rationed permits are usually issued on a first-come-first-served basis, by reservations, or by lottery. Most areas issue part of their permits on a first-come-first-served basis and part by reservation; only about 35 percent of the areas issue all permits by only one method. Typically, 15 to 20 percent of the people that reserve a permit fail to claim and use it.

Of the areas that do not ration, more than one-half do not have mandatory permits (table 15). Where permits are required, they usually are required of all users, although 10 percent of the areas only require permits for overnight camping and 4 percent require permits for specific types of users only.

Permits are required most frequently by the NPS. Only 24 percent of the NPS areas, as opposed to more than 50 percent of the areas administered by other agencies, neither require permits nor ration use. The NPS is also more likely to require permits for overnight-users only.

Regional differences are also pronounced. Permits are seldom required in the Midwest, Southeast, or Rocky Mountain States; they are usually required in the Northeast and Pacific States.

About one-half of the areas (53 percent) have a length-of-stay limit. Areas administered by the FWS and areas located in Northeast and Midwest States are particularly likely to have such limits. Limits have been placed on the number of nights at a campsite (17 percent of the areas) and on number of nights in the entire wilderness (29 percent of the areas). For both campsite and area-wide limits the statistical median and mode is 14 days; the range is 1 to 24 days for campsite limits and 1 to 30 days for area-wide limits.

Table 15.—Mandatory permits (if use is not rationed) (212 areas responding)

Agency and region	No	Yes for overnight camping	Yes to enter area	Only for specific users	Total
	Percent of areas				
Agency					
Forest Service	56	4	36	3	100
National Park Service	44	41	11	4	100
Fish and Wildlife Service	76	12	4	8	100
Bureau of Land Management	70	10	20	0	100
Region					
Northeast	33	17	33	17	100
Midwest	82	0	18	0	100
Southeast	76	8	12	4	100
Rocky Mountain	75	7	13	4	100
Pacific	17	17	66	0	100
Alaska and Hawaii	43	14	14	29	100
All areas	58	10	28	4	100

Distributing Use

Half of the areas attempt to disperse visitors more equally within the wilderness (table 16); fewer areas attempt to disperse use to other areas. The FS, in particular, has attempted use redistribution, particularly in Alaska, Hawaii, and the Northeast, Rocky Mountain, and Pacific Coast States. The vast majority of areas attempt dispersal by contacting visitors when a permit is issued. Visitors are usually told of crowded places and encouraged to go elsewhere.

Use distribution can be more subtly influenced by either improving or impeding access by road or trail. While this is being done in quite a few places (tables 17 and 18), most areas have a "maintain as is" policy for both trails and trailhead access roads. Selective upgrading of roads and road closures are more common than either construction of new roads or reduced maintenance. FS areas are most likely to upgrade roads, while NPS areas are most likely to close roads.

The most common trail policies involve building new trails and upgrading existing trails, along with designating trailless zones within the wilderness. Reducing maintenance and closing trails are much less common, except in areas administered by the BLM.

Table 16.—Use dispersal (247 areas responding)

Agency and region	Within area	To other areas
	Percent of areas that attempt to disperse use:	
Agency		
Forest Service	58	34
National Park Service	52	15
Fish and Wildlife Service	7	0
Bureau of Land Management	36	0
Region		
Northeast	50	43
Midwest	17	10
Southeast	28	13
Rocky Mountain	60	26
Pacific	51	29
Alaska and Hawaii	50	20
All areas	50	24

Table 17.—Access road policy

Road policy	Percent of areas				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Build new roads	9	2	0	18	7
Upgrade roads	26	10	10	0	20
Close roads	16	22	17	27	18
Reduce maintenance	6	6	7	9	6

Table 18.—Trail policy

Trail policy	Percent of areas				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Build new trails	25	20	10	27	22
Upgrade trails	44	33	10	36	37
Close trails	8	8	0	18	8
Reduce maintenance	18	8	0	18	14
Designate trailless zones	33	41	34	45	35

User Behavior and Type of Use

Many areas attempt to avoid problems by teaching visitors how to protect the wilderness resource or by regulating the type of use that occurs in the area. Over one-half of the areas have some type of minimum impact educational program (table 19). FS and NPS areas, in particular, have developed such programs; only one FWS area has a program. Educational programs are also much more common in the Rocky Mountain and Pacific Coast States than elsewhere. Several of the earliest educational programs originated in these regions, and it may be that areas in other regions have not yet had time or the incentive to develop such a program.

Almost one-half of all areas (48 percent) place a limit on the size of parties. This regulation is most common in FS areas (58 percent) and least common in FWS areas (10 percent). Party size limits, where instituted, range from 5 to 60 with a median of 15; the most common limit is 25.

Camping restrictions are common but highly variable; only 22 percent of the areas have no restrictions or guidance (table 20). Another 24 percent do not regulate camping but ask that people camp in certain locations. The most common advice is to camp on previously used sites in order to stop the spread of impacts. FS areas, however, more commonly advise people to camp on previously **unused** sites. This apparently is an attempt to reduce campsite impacts and loss of solitude by distributing users and their impacts more widely.

Where camping regulations exist, it is common to prohibit camping in certain locations, most commonly close to water bodies. Over one-third of the FS areas have this regulation. The camping setback from water bodies ranges from 20 ft to as much as one-half mile, but the most common distance is 100 ft. Similar setbacks from trails are common and range from 10 ft to one-half mile; again the most common distance is 100 ft.

Table 19.—Minimum impact education (239 areas responding)

Agency and region	Percent of areas offering:		
	No program	Map or brochure	Interpretive program
Agency			
Forest Service	40	60	30
National Park Service	35	61	48
Fish and Wildlife Service	95	5	5
Bureau of Land Management	64	27	27
Region			
Northeast	100	0	0
Midwest	67	33	17
Southeast	52	40	28
Rocky Mountain	45	55	27
Pacific	33	66	46
Alaska and Hawaii	38	63	25
All areas	44	54	30

Table 20.—Camping policies

Policies	Percent of areas				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
No regulations AND/BUT					
No guidance	26	4	[illegible]	55	22
Encourage visiting previously used sites	15	[illegible]	0	9	13
Encourage visiting previously unused sites	16	2	[illegible]	0	11
Camp anywhere EXCEPT					
In certain ecosystems	4	[illegible]	1	9	8
Close to water bodies	17	[illegible]	7	18	30
Close to trails	4	[illegible]	1	0	21
Close to other camps	[illegible]	8	0	0	5
Unspecified [illegible]	5	4	0	9	4
In closed areas	14	14	0	0	12
All campsites designated					
Throughout wilderness	2	18	0	0	5
Close to trails	1	10	7	0	4
In certain areas	[illegible]	16	[illegible]	0	5
No overnight-use allowed	1	4	59	0	9

Prohibitions on camping in certain ecosystem types are less common, except in the NPS. The most frequent regulation of this type prohibits camping in meadows.

The most severe restrictions require that visitors camp only on designated sites throughout the entire wilderness, close to trails, or in other specified locations. These restrictions are found in about 40 percent of the NPS areas but are uncommon elsewhere. Finally, 9 percent of the areas do not allow overnight use. Most of these are areas administered by the FWS and, to a lesser extent, the NPS.

About two-thirds of all areas place no restrictions on wood fires (table 21). FS and BLM areas seldom restrict fires, although in some cases they may be discouraged; NPS and FWS areas usually restrict fires. All campfires are prohibited in about one-half of the areas administered by these latter two agencies.

Although packstock use is prohibited in only 3 percent of all areas; there is no regular stock use in 62 (25 percent) of the areas. Where packstock use does occur, regulations are common, except in areas administered by the FWS. Restrictions are most common in NPS areas; only 10 percent of the NPS areas have no packstock regulations (table 22).

The most common regulations limit the number of stock and prohibit use near water bodies, except for watering or when traveling. Where limits have been imposed, the number of stock allowed ranges from 5 to 50, with 20 the most common limit. The most common setback from water bodies is 200 ft.

Most other stock regulations are uncommon, except in areas administered by the NPS. A majority of NPS areas prohibit

stock use on selected trails, require stock to carry their own feed, and prohibit the use of certain restraining methods, usually loose herding, picketing, and tying horses directly to trees. About 40 percent of the NPS areas also prohibit the tying of horses in camps and require the use of specially designated stock camps. Few areas have instituted seasonal restrictions.

Table 21.—Wood fire policy

Policy	Percent of areas				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
No regulations AND/BUT					
No guidance	61	8	24	73	47
Fires discouraged	20	16	0	36	18
Fires prohibited					
Everywhere	1	43	59	0	15
Except in designated places	6	20	3	0	8

Site Management

Managers have also closed individual campsites or larger areas to use in an attempt to reduce or redistribute resource impacts. Closed campsites can be found in 37 percent of the areas. They are most common in NPS areas (43 percent) and least common in FWS areas (17 percent). The most common reason for closure is overuse and resource damage; closures around lakeshores are also common. In about 40 percent of these areas, all of the closures are temporary, despite consistent research results which suggest that campsite rest-rotation is not feasible because recovery periods are so lengthy (Merriam and others 1973).

Area closures to all use are much less common. They occur in only 11 percent of the areas, primarily in areas administered by the NPS and FWS. The most common reason for closure is a conflict between recreationists and wildlife. Most of these closures are permanent.

Table 22.—Packstock policies

Policy	Number of areas (Percent of areas with regular stock use)				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
No restrictions	44 (31)	3 (10)	7 (70)	4 (44)	58 (31)
Limit on number of stock	61 (43)	17 (57)	0 (0)	2 (22)	80 (42)
Prohibited on some trails	25 (18)	22 (73)	0 (0)	0 (0)	47 (25)
Prohibit confinement near water	61 (43)	4 (13)	0 (0)	1 (11)	66 (35)
Seasonally prohibited	4 (3)	4 (13)	1 (10)	0 (0)	9 (5)
Prohibited in camps	16 (11)	12 (40)	0 (0)	1 (11)	29 (15)
Allowed only in stock camps	0 (0)	11 (37)	0 (0)	0 (0)	11 (6)
Grazing by permit only	9 (6)	4 (13)	0 (0)	0 (0)	13 (7)
Must carry own feed	27 (19)	27 (90)	1 (10)	1 (11)	56 (29)
Restrictions on restraining methods	34 (24)	17 (57)	0 (0)	0 (0)	51 (27)

Of the areas that do have campsite closures, only 16 percent have a program to actively assist the revegetation of closed sites. All of these are FS or NPS units. Other areas, however, may eliminate user-built facilities and attempt to hide evidence of previous use. Currently there is some debate about how much and what types of assisted revegetation are appropriate in wilderness, but given the lengthy natural recovery periods of most impacted campsites, active revegetation programs are likely to become increasingly important. Where revegetation programs have been initiated, transplanting is more common than seeding. A number of areas also scarify the soil and use fertilizers and organic mulches.

One of the most obvious signs of human use on campsites is a fire ring. Managers have frequently tried to reduce this visual impact by removing fire rings. Although only 21 percent of the areas make no attempt to remove fire rings (table 23), there is little consensus about appropriate fire ring removal policy, even within agencies. The FS is most likely to either remove all fire rings or to remove only selected "undesirable" rings. The other agencies, where they do not remove all rings, are most likely to leave one fire ring on each campsite.

A considerable number of areas also "improve" campsites. The most common facilities are open-pit toilets (19 percent), enclosed outhouses (15 percent), shelters (12 percent), constructed fireplaces (10 percent), tables (8 percent), and a potable water supply (7 percent). Surface hardening is very rare on campsites and, except for corduroy and some soil cement, is rare on trails. In general, it appears that site hardening has not been deemed appropriate or necessary in most areas.

Table 23.—User-built fire ring policy

Policy	Percent of areas that permit user-built rings				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Remove all fire rings	29	30	17	18	27
Remove all rings but one on each campsite	16	30	25	27	19
Remove only selected "undesirable" rings	38	25	0	9	33
Don't remove fire rings	17	15	58	46	21

Effective Management Techniques

The majority of managers thought that the "most effective" management technique was personal contact with the visitor, leading to increased use dispersal and improved camping techniques. Many indicated that a permit system, brochures, and maps also helped achieve these ends. Managers of more heavily used areas commonly mentioned rationing and trailhead quotas, restricting campers to designated camps, closure of fragile areas and overused campsites, and reducing access by restricting parking capacity, making trailhead access more difficult, or reducing trail maintenance. Campfire prohibitions, restrictions on stock use, reductions in maximum party size, and lakeshore setbacks were also considered to be the most effective management technique in at least three areas.

PLANNING AND ADMINISTRATION

Management Plans

How wilderness management plans are written differs between the various managing agencies. In the FS and FWS, separate wilderness management plans have generally been prepared although the National Forest Management Act recently stated that wilderness plans will now be part of an overall National Forest plan. In the NPS, wilderness plans are usually incorporated into management plans for the park unit as a whole (formerly called "master plans"). FS plans are usually prepared by the administering forest staff, or in some cases, by special planning teams, as in the case of the Alpine Lakes and Hells Canyon Wildernesses. NPS plans are usually written by specialists from the Denver Service Center with local park staff assistance.

The FS is considerably ahead of the other agencies in having plans either completed or in preparation; only 7 percent of the FS areas have not started or completed a plan (table 24). In contrast, almost one-half of the refuges have not started as yet, though this may be accounted for by the fact that general management of the refuge may dictate much of the management direction in the wilderness portions.

Table 24.—Status of wilderness plans (including all refuges that responded, regardless of recreational use)

Status of plans	Number of areas (percent)				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Have a plan	79 (48)	17 (35)	10 (22)	5 (46)	111 (41)
Plans being prepared	73 (45)	15 (30)	14 (30)	4 (36)	106 (40)
No plan being prepared	11 (7)	17 (35)	22 (48)	2 (18)	52 (19)
Total	163 (100)	49 (100)	46 (100)	11 (100)	269 (100)

Wildfire Management

Reestablishing natural fire in wilderness is a fairly recent development. On the whole, less than one-half (46 percent) of the NWPS and likely additions are applying a natural fire policy (table 25). The FS and NPS are most likely to do so; the BLM primitive areas are least likely to do so.

Scheduled prescribed burning, whereby fire is purposely ignited by management to either reduce fuels or manipulate ecological communities, is less often applied (8 percent of all areas). The FWS and NPS are much more likely to do this than the other agencies. Fire plans are not widespread either; only about one-quarter of the areas have them.

Table 25.—Restoring the natural role of fire and scheduled prescribed burning

Status	Number of areas (percent of all areas)				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Have restored (or will soon) natural role of fire	81 (50)	23 (49)	18 (37)	3 (27)	125 (46)
Are using scheduled prescribed burning	2 (1)	9 (18)	10 (20)	0 (0)	21 (8)
Have a fire plan	28 (17)	17 (36)	20 (41)	4 (36)	69 (26)

Personnel Requirements

Our intention was to find out how large a staff was required to manage each area during the main use season, both inside the area and at the trailheads. The results reported may or may not include trail crews (as this was not specified in the questionnaire).

Because the areas vary greatly in size, trail net, and recreational use, comparisons based on these variables seem useful (table 26). The acres per employee vary considerably between agencies, suggesting that this is a poor indicator of staff coverage. For example, Glacier Bay National Monument has 2.25 million acres of proposed wilderness covered by four field personnel; at least 90 percent of this area, however, is virtually inaccessible, virtually unused, and not patrolled. Comparisons of miles of trail and visitor-days per employee seem more useful. Even these exhibit substantial variability, with the greatest trail coverage in the BLM areas and the least in the FWS areas where trail nets are small and relatively unimportant. Visitor-days per employee are much higher in the FS areas than in areas administered by other agencies.

Table 26.—Wilderness management personnel (areas with designated wilderness management personnel)

Coverage of field personnel by:	Median number of acres, miles of trail, or visitor-days				
	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Management	All agencies
Acres (Number of acres divided by number of field personnel)	22,300	39,500	2,250	16,750	22,994
Miles of trail (Number of miles of trail divided by number of field personnel)	29	16	1	60	26
Visitor-days (Number of annual visitor days divided by number of field personnel)	9,420	2,300	3,510	4,600	7,900

LEGACIES OF LEGISLATION

Although the NWPS was established primarily for purposes of preservation,scientific values, and wilderness recreation, the original and subsequent legislation designating wilderness expanded these purposes substantially and complicated wilderness management considerably by specifying additional uses that could be allowed. Additionally, the boundaries for areas that Congress outlined have in many cases had inadvertent effects on management. The extent of "allowable but nonconforming uses" and boundary related problems comprise an important dimension of wilderness management that deserves attention.

Boundary Problems

Almost one-half of all areas (42 percent) indicate that the established boundaries had led to problems. Boundary problems were most common in FS areas (46 percent) and least common in FWS areas (28 percent).

The situations and resulting problems are varied. Some are legal problems of definition, such as conflicts with State jurisdiction in the case of the San Juan Islands National Wildlife Refuge (where small islands designated as wilderness are delineated by the mean high-tide line). In a number of cases (8 percent), the boundaries were indefinitely defined by Congress on small scale maps.

Nontopographic boundaries were the most frequently mentioned problem (22 percent). In some instances, boundaries not related to topography complicate surveying and locating boundaries. Extensive posting is required to prevent unwitting intrusions by inappropriate activities. In other areas, established boundaries bisect lakes or old roads are included in the wilderness. Elsewhere, the existing trail net does not fit; trails frequently wander in and out of the wilderness.

Extensive and significant problems also result from the inclusion of areas with heavy use of a nonwilderness character. In these areas the manager is faced with either accepting the situation or resorting to costly use controls to alter these traditional use patterns. A prime example is the Marion Lake area in the Mt. Jefferson Wilderness, which receives crowds of day-users, many bringing in wheelbarrows full of fishing gear and beer on the short and easy trail.

Finally, many managers mentioned the lack of buffering, resulting in noise and visual intrusions, and pollution and trespass problems. In one case, locating the boundary next to a major highway results in wilderness impacts from highway maintenance as well as intrusions by highway motorists.

Other Uses of Wilderness

The Wilderness Act specifically provided for a variety of uses of wilderness in addition to "recreation of a primitive and unconfined nature." These "nonconforming uses" include such activities as mining, livestock grazing, and previously established motorized vehicle use and aircraft landing. In some wildernesses there is "overlaid" legislation (such as designation of National Scenic Trails or Wild Rivers), or administrative designations by the agencies (such as Research Natural Areas). All of these affect wilderness management to varying degrees.

Managers were asked to report whether these uses exist in their area and the extent to which they contribute to a problem. They were also asked similar questions about a variety of facilities and equipment in their area, ranging from cabins to research installations. Table 27 reports these for agencies only in designated wildernesses.

There are significant differences between the three agencies administering wilderness with respect both to the extensiveness of these other uses and also the extent that they are considered problems. These uses are almost all less common in the refuges than the other units; the major exception is motorboat use,

Table 27.—Other uses, facilities, and special conditions found in the National Wilderness Preservation System (184 areas responding)

Use, facility, or condition	Percent of wildernesses where situation exists and: —is not a problem (NP) —is a problem (P)							
	Forest Service		National Park Service		Fish and Wildlife Service		All agencies	
	NP	P	NP	P	NP	P	NP	P
1. Livestock grazing	39	13	12	4	8	2	32	10
2. Private inholdings engaged in commercial agriculture or livestock operations	9	1	0	12	4	2	7	3
3. Private inholdings used for private recreation enterprise (resorts, backcountry camps, etc.)	7	4	4	4	2	0	6	4
4. Private inholdings used for personal subsistence or personal recreation	17	3	12	4	2	2	15	3
5. Cabins or other existing structures (other than those retained for historic value)	45	6	24	16	6	2	39	7
6. Mineral and fossil fuel claims and developments	34	11	12	0	0	0	28	9
7. Historical or archeological sites on national registers	12	1	44	4	8	0	16	1
8. Historical or archeological sites not on national registers	43	7	64	8	29	0	46	7
9. Motorized boat use allowed as a preexisting condition	3	4	8	4	24	2	7	4
10. Motorized ground vehicle use allowed as a preexisting condition	2	5	0	4	2	2	2	5
11. Fixed-wing aircraft landing fields on Federal land open for public use	3	1	4	0	0	2	3	1
12. Fixed-wing aircraft landing fields on private inholdings	3	1	4	0	0	0	3	1
13. Fixed-wing aircraft landing fields for administrative use only	2	0	0	0	0	0	2	0
14. Constructed heliports	18	0	0	0	0	0	14	0
15. Water impoundments	25	4	32	8	22	2	26	6
16. Fish-stocking within the wilderness	53	4	8	0	2	0	42	3
17. Snow or watercourse survey equipment—telemetry-operated	5	0	8	0	2	0	5	0
18. Snow or watercourse survey equipment—manually-operated	19	1	12	0	4	0	17	1
19. Electronic transmission facilities (microwave, powerlines, etc., other than for administrative communication)	4	0	20	4	8	0	6	1
20. Ongoing research projects	30	2	64	4	28	0	34	2
21. Research installations	4	1	20	0	4	0	6	1
22. Research Natural Areas within the wilderness	6	0	20	0	26	0	11	0
23. National Scenic Trails within the wilderness	15	9	8	0	0	0	13	7
24. Wild Rivers within or adjacent to the wilderness	11	1	8	0	0	0	9	1

which is most frequent in the refuges. The FS areas have the greatest variety of nonconforming uses and situations. In particular, grazing, private holdings, and mining are widespread and troublesome in FS wilderness. Electronic transmission facilities tend to be most frequent in the NPS units, as are problems with grazing, inholdings, and cabins and other structures. Research projects and research installations occur more frequently in the NPS areas but apparently cause few problems.

Three types of legislative or administrative designations may be superimposed on (or bisect) wilderness that merit attention: National Scenic Trails, Wild Rivers, and Research Natural Areas. The first two have received some attention because they tend to conflict or at least differ in some respects from wilderness management direction. Of the 20 percent of areas reporting National Scenic Trails in wilderness, over one-third regard this situation as a problem, largely because the legislative mandate for the trail system encourages use and allows more elaborate trail and facility development standards than is consistent with wilderness. Interestingly, none of the NPS areas perceive this as a problem. Wild Rivers seem to pose less of a problem or conflict in wilderness.

Generally, most of these other uses and special situations prevail in the Western United States. Grazing, both on Federal land and private inholdings, is more extensive and troublesome in the Pacific and Rocky Mountain regions. Other inholdings, used for commercial or personal recreation use by the owners, are more typical of the Midwest. Fish stocking in wilderness occurs most frequently in the Pacific region.

Mineral and fossil fuel activities seem particularly worthy of attention. With increasing values of rare metals and energy sources, the NWPS has come to, and will no doubt continue to, bear increasing pressure to explore for and extract these resources. Though our results do not allow us to distinguish between resources sought in each area, managers did provide a profile of the claims and activities in their area.

Table 28 shows the total number of claims managers **think** there are; claim records are generally kept by the counties, not the agency. It also shows the number likely to be declared valid and thus remain in effect after 1983, the Wilderness Act deadline for validating claims. More than one-half of the claims are located in the FS units; the NPS areas have proportionately much fewer. Nevertheless, NPS managers report the highest proportion of claims likely to prove valid, perhaps because recent legislative restrictions have winnowed out marginal claims.

Table 28.—Mineral claims in the National Wilderness Preservation System and likely additions

Agency	Number of claims (percent of all claims)	Number likely to be declared valid	Percent likely valid
Forest Service	15,295 (62)	9,721	64
National Park Service	2,832 (12)	2,159	76
Fish and Wildlife Service	3,996 (16)	1,998	50
Bureau of Land Management	2,398 (10)	1,009	42
All agencies	24,521 (100)	14,887	61

CONCLUSION

This survey of the National Wilderness Preservation System reveals the diversity of the system. The tremendous range of physical and ecological conditions is in itself impressive. Variations in the amount and type of recreational use, as well as the nonconforming uses allowed, contribute to further diversity. Furthermore, the system is managed by four Federal agencies, each with differing traditions, philosophies, and legislative mandates.

In spite of such diversity, most of the NWPS components share common problems. Resource degradation and loss of solitude due to recreational use are troublesome problems in a majority of areas. Given that managers share these common problems, one would expect their responses to converge on certain techniques or approaches to deal with them. Results of this survey, however, indicate that consistent responses to similar situations are rare.

Differences in the management philosophies of the agencies administering the NWPS are a major source of this inconsistency. Bury and Fish (1980) and Fish and Bury (1981) also comment on these differences in agency outlook. The NPS is pursuing a particularly aggressive management program. In comparison to the other agencies, more NPS areas have established carrying capacities and have instituted regulations to control amount and type of recreational use. Management of areas administered by the FWS and BLM has been particularly passive in comparison. Few of these areas have established capacities and, with the exception of rules to protect wildlife in refuges, regulations are rare.

If the aggressiveness of management is primarily a reflection of need, one would expect amount of use and related problems to be especially severe in NPS areas and especially low in FWS and BLM areas. Although use densities and problem severity are generally lower than average in FWS and BLM areas, NPS lands do not appear to have critically high use densities or problems.

Use per trail mile is about average in NPS areas, and use per acre is considerably lower in NPS areas than in FS areas. This suggests that NPS trails are well used, but the areas as a whole are not. Opportunities for low density recreation away from trails may be greater in NPS areas than in FS areas. Thus, NPS areas do not seem to be more intensely used than FS areas.

Problems with crowding and resource damage appear to be more pronounced in FS areas than in NPS areas. Although our survey was based on managers' perceptions—not objective measurement—such perceptions shape management policy.

Use more frequently exceeds carrying capacity—or would if rationing had not been instituted—in FS areas than in NPS areas. Again, it appears that the need for management is greater in the FS than in the NPS; and yet, it is the NPS areas that are more highly regulated. Although the lower incidence of problems in NPS areas may be a result of greater regulation, NPS managers, at least in comparison to FS managers, usually institute regulations at lower levels of crowding and resource damage.

The implication is that the management direction of wilderness units is largely a function of the philosophy and tradition of an agency. The NPS emphasizes extensive use without impairment of the resource. As Bury and Fish (1980) suggest, the primary objective of resource preservation has led NPS managers to institute controls before damage occurs. The effects of these controls on the visitor's experience is a secondary concern. In contrast, the FS tradition of largely unfettered recreational use has led to an emphasis on freedom of choice for the user. Restrictions have generally been applied only after significant resource damage and loss of solitude have occurred. Preservation of wildlife has been the primary objective in FWS areas, and restrictions are generally lacking except where recreationists conflict with wildlife. In cases of anticipated conflict, however, highly restrictive measures have been quickly taken. A management tradition has not developed on BLM lands. Perhaps because of low use, management has been largely permissive.

Management varies considerably within agencies. The NPS, for example, frequently rations use, but the means of rationing varies. Some areas, such as Yosemite and Sequoia-Kings Canyon National Parks, establish trailhead quotas but institute no internal restrictions on freedom of movement. Other areas, such as Mt. Rainier and Glacier, ration use by campsite, requiring visitors to keep to an itinerary developed prior to entering the area. In the FS, establishment of carrying capacities has been specifically mandated, but there is no consistent method for establishing capacities. Most areas are independently developing a system. This lack of consistency is not entirely bad. Different environmental and use situations demand some flexibility in management. Moreover, differing management strategies provide a diversity of recreation opportunities for the visitor. Inconsistent management across the NWPS does, however, create its own problems. In some wildernesses, visitors are encouraged to camp at previously used sites with established fire rings; in other areas, which may have quite similar environments and amounts of use, visitors may be encouraged to use previously unused sites and to scatter existing fire rings. Teaching the visitor how to behave, a recent emphasis in wilderness management, will be extremely difficult if management policies are confusing and contradictory. Lack of consistency may compromise cooperative management of adjacent areas and may even invite legal challenge.

Clearly, management of the NWPS could be improved. Despite the presence of unique situations and varied sizes, environments, and use situations, most wilderness units share a few common problems. Various solutions have been tried and some are working. There has been little sharing of experience; consequently, the best solutions have not always been implemented and management across the NWPS has been inconsistent.

More communication and cooperation between units with similar problems would improve management. Data in the appendix of this report should help managers identify alternative responses to problems, areas with similar problems, and areas that have tried various management techniques. Managers could utilize this information to profit from each other's experience, leading ultimately to a more consistently and efficiently managed NWPS.

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APPENDIX A—TABULAR SUMMARY OF MANAGER RESPONSES

In the following tabular summary, the answers to most questions are given by area. (Questionnaire is available from Wilderness Management Research Unit, Forestry Sciences Laboratory, Missoula, MT 59806.) The 252 units for which we report data are organized by agency and status, and within these categories by region, from Alaska and Hawaii south and east to Florida.

To enable readers to readily find an area of interest, an alphabetical index is provided in appendix B. Some wildernesses are comprised of several National Forests; in such cases a questionnaire was sent to each one. Responses will therefore be identified by several numbers. For example, number 75 applies to the Gallatin National Forest portion of the Absaroka-Beartooth Wilderness; number 76 applies to the Custer National Forest portion.

The list terminates with FWS areas that were surveyed but not reported in detail because they receive minimal recreational use (numbers 253–308). Each area is located by State and by number on the location map (fig. 2).

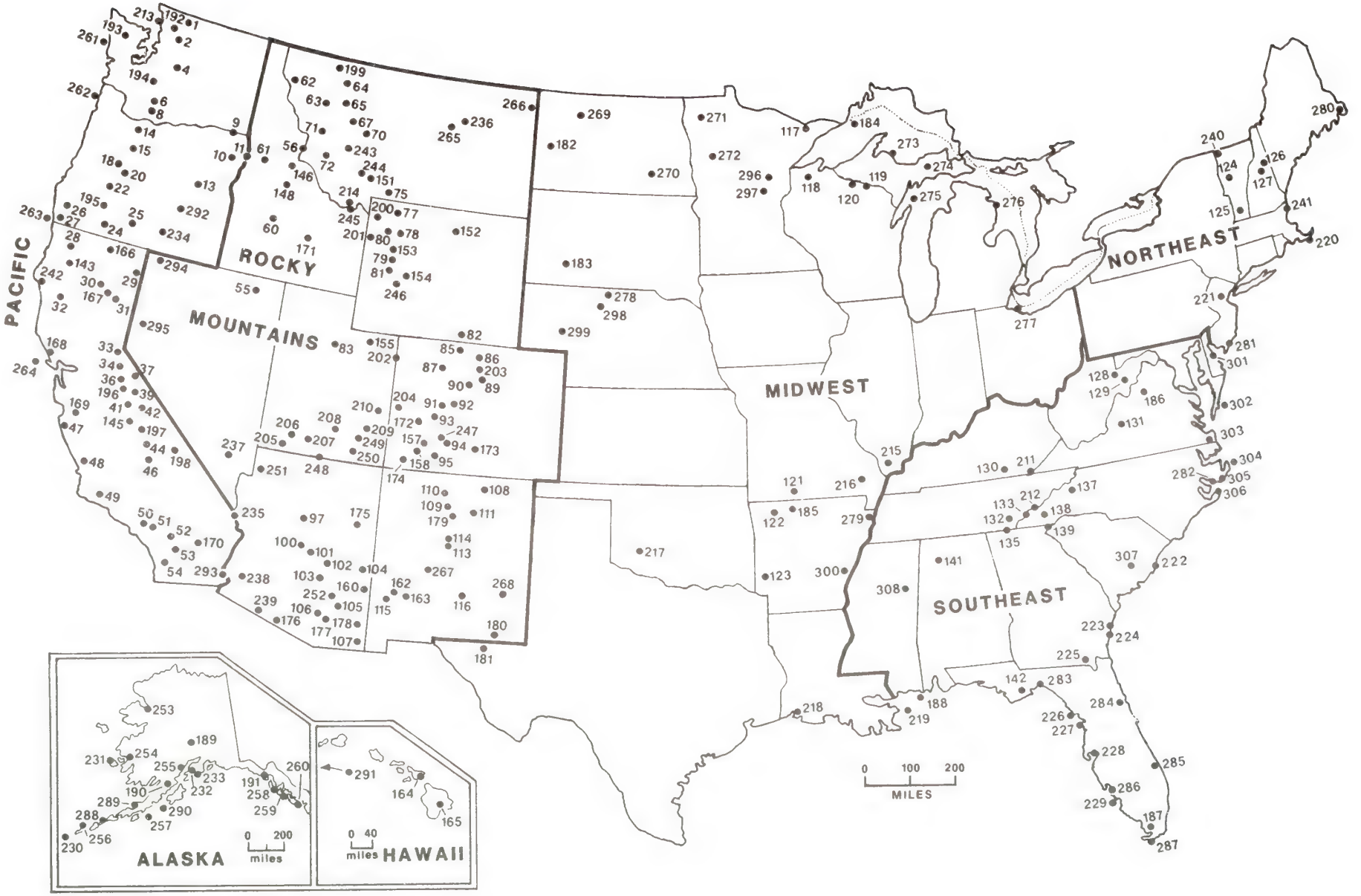

Figure 2.—Wildernesses and likely additions to the National Wilderness Preservation System that were surveyed in this study. Each area is listed, by number, in appendix B.

Table 29.—Area and use characteristics

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors					Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques					
					Day-users	With packstock	With outfitters	With outdoor education programs	Hunters			Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
F.S. WILDERNESS																	
1 Pasayten	398	61	690	7-9	05	32	10	11	25	5.7	3	-	X	-	X	-	X
2 Glacier Peak	228	70	110	7-9	02	05	01	02	08	3.3	3	-	-	-	X	-	-
3 Glacier Peak	237	47	240	7-9	04	07	01	01	20	2.0	3	X	-	-	X	-	-
4 Alpine Lakes	122	82	91	7-9	10	07	02	05	10	2.5	1	X	X	X	-	-	-
5 Alpine Lakes	185	229	369	7-9	10	03	01	01	10	2.0	3	X	X	-	-	-	-
6 Goat Rocks	23	35	26	7-9	10	05	01	01	11	2.0	1	X	-	-	X	-	-
7 Goat Rocks	60	30	88	7-9	15	03	01	01	07	5.8	2	-	X	-	X	-	-
8 Mount Adams	42	01	60	7-9	65	10	02	05	03	3.0	3	X	-	-	-	-	-
9 Wenaha-Tucannon	177	28	165	10,11	05	75	15	00	85	4.0	3	X	X	X	-	-	-
10 Eagle Cap	294	53	500	7-8	20	22	09	02	10	4.0	3	-	-	-	X	-	-
11 Hells Canyon[d]	110	10	300	10,11	02	95	75	00	90	5.0	3	X	-	-	-	-	-
12 Hells Canyon	60	04	105	7-8	20	05	02	01	05	2.0	1	X	X	X	-	-	-
13 Strawberry Mountain	34	06	67	7-8	52	02	01	00	05	3.0	3	-	X	X	-	-	-
14 Mount Hood	47	49	116	7-9	36	02	00	01	01	2.0	3	-	X	X	-	-	-
15 Mount Jefferson	4	01	03	7-9	30	02	00	00	00	3.0	4	-	-	-	X	-	-
16 Mount Jefferson	64	49	110	6-9	30	04	00	00	05	1.5	3	X	-	X	-	-	-
17 Mount Jefferson	33	09	51	8-9	15	03	01	00	01	3.1	1	-	-	X	-	-	-
18 Mount Washington	38	08	29	7-9	65	02	00	00	12	1.9	1	X	-	X	-	-	-
19 Mount Washington	8	01	05	7-8	75	05	00	00	50	3.1	4	X	-	-	-	-	-
20 Three Sisters	182	38	240	7-9	30	06	01	05	08	3.4	3	X	-	X	-	-	-
21 Three Sisters	63	44	79	7-9	25	03	01	05	01	2.0	1	X	-	X	-	-	-
22 Diamond Peak	16	02	24	6-8	40	02	00	UK	18	2.0	3	-	-	X	-	-	-
23 Diamond Peak	20	03	38	7-8	69	03	00	00	00	1.5	3	-	X	X	-	-	-
24 Mountain Lake	23	04	21	7-8	30	05	02	01	02	2.5	3	X	X	X	-	-	-
25 Gearhart Mountain	19	02	14	7-8	52	01	00	00	15	2.3	3	X	X	X	-	-	X
26 Wild Rogue	37	28	16	6-9	23	00	80	05	00	2.0	3	-	X	X	X	-	X
27 Kalmiopsis	169	05	170	6-8	60	02	01	00	05	3.0	3	X	X	X	-	-	-
28 Marble Mountain	214	88	348	7-9	05	03	05	00	14	6.0	3	X	-	-	X	-	-
29 South Warner	69	14	90	6-9	10	15	01	00	15	9.0	3	-	-	-	X	-	-
30 Thousand Lakes	16	16	20	5-8	10	10	00	00	05	2.0	1	X	-	-	X	-	-
31 Caribou	19	21	26	6-8	35	06	00	00	02	4.0	3	-	X	-	X	-	-
32 Yolla Bolly-Middle Eel[d]	39	05	60	7-9	20	10	01	00	10	3.0	2	X	X	-	X	-	X
33 Desolation	63	302	79	7-8	20	01	01	00	00	2.5	3	X	-	-	X	-	-
34 Mokelumne	40	34	50	7-9	10	05	00	00	05	2.0	3	X	-	-	X	-	-
35 Mokelumne	10	06	08	7-9	08	05	01	02	04	5.0	3	X	-	-	X	-	-
36 Emigrant	104	106	185	6-8	05	13	05	05	03	4.2	3	-	X	-	X	-	-
37 Hoover	39	55	65	6-9	30	02	01	01	03	2.5	3	-	X	-	X	-	-
38 Hoover	9	12	14	9-10	50	01	01	01	05	4.3	3	X	-	-	X	-	-
39 Minarets	43	68	77	7-9	04	08	01	05	03	2.5	3	X	-	-	X	-	-
40 Minarets	59	174	69	7-8	11	05	04	05	01	6.5	3	-	-	-	X	-	-
41 Kaiser	23	07	35	7-8	28	02	02	UK	01	1.6	3	-	X	-	X	-	-
42 John Muir	260	372	300	7-8	10	02	02	01	01	4.0	3	X	-	-	-	-	-
43 John Muir	223	604	214	7-8	15	05	07	01	01	6.9	3	-	X	-	X	-	-
44 Golden Trout	137	19	177	6-9	20	40	20	00	15	3.0	3	X	-	-	-	-	-
45 Golden Trout	169	40	232	7-8	08	30	10	05	04	9.0	1	X	-	-	X	-	-

See footnotes at end of table 29, p. 23

Table 29.—(con.)

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors					Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques					
					Day-users	With packstock	With outfitters	With outdoor education programs	Hunters			Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
46 Domeland	63	11	30	5-8	10	25	01	05	10	2.0	3	X	X	-	X	-	-
47 Ventana	161	180	200	4-5	09	02	00	01	03	2.8	4	X	-	-	X	-	-
48 Santa Lucia	21	02	25	6-9	95	01	00	00	02	1.5	1	X	-	-	-	-	-
49 San Rafael	149	51	170	3-6	10	05	00	03	10	1.5	3	X	-	X	-	X	-
50 San Gabriel	36	46	10	---	45	01	00	03	05	2.5	3	X	X	X	X	-	-
51 Cucamonga	9	19	17	6-7	54	01	00	02	03	2.0	1	-	-	-	X	-	-
52 San Gorgonio	35	274	78	6-8	05	01	00	00	01	1.5	3	-	-	-	X	-	-
53 San Jacinto	22	117	UK	7-8	44	01	01	03	00	2.0	1	-	-	-	X	-	-
54 Aqua Tibia	16	06	14	4-6	70	01	00	10	10	3.0	3	X	X	-	X	-	X
55 Jarbidge	65	11	146	7-10	56	13	15	02	50	3.0	1	-	-	X	-	-	-
56 Selway-Bitterroot	259	50	439	7-9	05	50	20	03	35	3.0	3	X	X	X	X	-	X
57 Selway-Bitterroot	560	42	700	6-9	05	25	12	00	20	5.5	3	-	X	-	-	-	-
58 Selway-Bitterroot	406	73	488	7-9	31	32	08	01	33	4.0	3	X	X	X	X	X	-
59 Selway-Bitterroot	10	01	08	7-10	40	25	00	10	30	2.5	3	X	-	X	-	-	-
60 Sawtooth[d]	55	60	307	7-8	53	06	11	01	01	4.6	3	-	X	X	X	-	X
61 Gospel Hump	206	04	250	8-10	25	30	05	01	50	3.0	3	X	X	-	-	-	-
62 Cabinet Mountains[d]	50	06	95	7-8	70	03	00	00	05	2.0	1	-	X	X	-	-	X
63 Mission Mountains	74	15	40	7-9	80	05	00	00	02	2.0	3	-	-	X	-	-	-
64 Great Bear	286	120	280	7-11	07	65	25	00	55	4.0	3	X	-	-	-	-	-
65 Bob Marshall	709	150	750	7-9	05	50	30	01	20	6.0	4	X	-	-	-	-	-
66 Bob Marshall	300	32	307	7-8	05	36	10	00	26	5.2	3	-	X	X	-	-	-
67 Scapegoat	75	15	68	7-10	11	30	03	UK	15	5.0	3	X	X	X	-	-	-
68 Scapegoat	81	06	150	7-10	05	20	05	02	20	2.0	3	X	X	-	-	-	-
69 Scapegoat	84	09	114	7-8,11	05	45	12	00	29	5.7	3	-	X	X	-	-	-
70 Gates of the Mountain	29	04	43	7,8,10,11	25	40	00	00	50	3.0	1	X	-	X	-	-	-
71 Welcome Creek	28	02	25	7,8,10,11	75	15	00	00	60	3.0	3	X	-	X	-	-	-
72 Anaconda-Pintler	41	06	52	7-8,10	25	50	05	00	25	3.0	3	X	-	X	-	-	X
73 Anaconda-Pintler	45	14	100	6-8	20	10	03	01	15	2.5	3	-	-	X	-	-	X
74 Anaconda-Pintler	73	09	127	9-11	70	30	08	01	10	4.0	3	X	-	X	-	-	X
75 Absaroka-Beartooth	576	200	350	9-10	50	50	05	01	60	4.0	3	X	X	-	-	-	-
76 Absaroka-Beartooth	346	98	173	7-8	33	05	01	04	02	3.0	3	X	X	X	X	-	X
77 North Absaroka	351	17	89	7-10	20	58	30	10	55	5.0	3	X	X	X	X	-	-
78 Washakie	687	56	380	7-8,10	33	70	40	04	40	4.0	3	X	X	X	-	X	X
79 Fitzpatrick	191	31	94	7-8	15	10	08	23	04	4.4	3	X	X	X	X	-	-
80 Teton	557	57	400	7-10	10	95	65	05	12	6.0	2	X	X	-	-	-	X
81 Bridger	392	265	576	7-8	10	03	02	04	04	5.0	3	X	-	X	-	-	-
82 Savage Run	15	15	12	7-8,10	90	10	05	00	40	3.0	1	X	X	-	X	-	-
83 Lone Peak	10	02	12	---	100	00	00	00	00	1.0	1	X	X	X	-	-	X
84 Lone Peak	20	09	30	6-9	80	05	00	00	05	2.0	1	X	X	-	-	-	X
85 Mount Zirkel	72	35	200	7-8	04	01	01	02	01	4.0	3	X	X	-	-	-	-
86 Rawah	27	24	75	6-9	28	05	01	01	05	2.0	1	-	X	X	-	X	X
87 Flat Tops	39	17	33	7-8	35	35	20	05	15	3.0	3	-	X	-	-	-	-
88 Flat Tops	196	89	234	7-10	50	25	15	01	15	3.0	3	X	-	-	-	-	-
89 Indian Peaks	70	162	110	7-8	60	04	04	02	05	2.0	1	X	X	-	-	-	X
90 Eagles Nest[d]	51	81	180	7-8	56	04	02	05	01	4.0	3	-	X	X	-	-	-

See footnotes at end of table 29, p. 23

Table 29.—(con.)

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors					Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques					
					Day-users	With packstock	With outfitters	With outdoor education programs	Hunters			Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
91 Maroon Bells-Snowmass	71	90	70	7-9	38	01	01	01	01	3.0	1	X	X	-	-	-	-
92 Hunter Fryingpan	74	03	59	7-8,10	20	35	02	03	30	2.5	3	X	-	-	-	-	-
93 West Elk	61	50	45	7-8,10	05	12	02	01	30	3.5	3	X	X	X	-	-	X
94 La Garita[d]	24	21	51	7-9	20	45	25	00	10	5.0	3	X	-	X	X	-	X
95 Weminuche	276	167	280	6-8	32	22	17	02	07	2.0	2	-	X	X	-	-	X
96 Weminuche	126	54	152	7-8	12	28	15	20	12	5.0	4	X	X	X	-	-	X
97 Sycamore Canyon	7	01	00	3-5,9-10	80	00	00	05	15	2.0	2	X	-	-	-	-	-
98 Sycamore Canyon	20	05	25	3-5	50	25	00	05	05	3.0	3	X	-	X	-	-	-
99 Sycamore Canyon	21	10	11	5-6	75	05	00	00	05	3.0	1	X	X	-	-	-	-
100 Pine Mountain[d]	9	04	20	4-5	25	15	05	15	15	2.0	3	X	X	X	-	X	X
101 Mazatzal	205	12	18	10	30	35	05	01	60	2.0	3	X	-	-	-	-	-
102 Sierra Ancha	21	10	40	9-10	80	10	00	00	40	2.0	3	X	-	-	-	-	-
103 Superstition	124	232	140	1-2	80	20	20	00	25	3.0	1	-	X	-	-	-	-
104 Mount Baldy	7	05	14	6-8	47	01	01	00	02	3.0	3	X	-	X	-	-	-
105 Galiuro	53	10	65	5,8-9	01	10	00	00	05	4.0	3	X	-	X	-	-	-
106 Pusch Ridge	56	60	105	---	93	00	00	01	01	2.0	3	X	X	-	-	-	X
107 Chiricahua	18	04	52	6-9	70	02	00	03	03	2.0	3	X	-	X	-	-	-
108 Wheeler Peak	6	20	14	6-8	75	10	01	UK	02	2.5	3	X	-	-	X	-	-
109 San Pedro Parks	41	24	38	7-9	31	08	00	00	05	3.5	3	-	-	X	X	-	-
110 Chama River Canyon[d]	48	01	01	5,9	10	05	00	00	00	2.0	4	X	-	-	-	-	-
111 Pecos	25	15	55	6-8	10	12	05	01	10	5.0	3	-	-	-	X	-	-
112 Pecos	144	130	250	6-8	25	08	01	01	07	2.0	3	-	X	-	X	-	-
113 Manzano Mountains	37	09	20	6-8	70	05	00	00	15	2.0	1	X	-	-	-	-	-
114 Sandia Mountains	31	35	55	---	90	01	01	01	06	2.0	1	X	X	-	-	-	-
115 Gila	430	90	410	5,7	04	09	04	04	04	3.5	1	X	X	-	X	-	-
116 White Mountain	31	29	46	6-8	20	30	01	00	21	3.0	1	X	-	-	-	-	-
117 Boundary Waters Canoe Area	1076	970	1600	6-8	60	00	05	01	01	4.0	1	X	-	-	X	-	-
118 Rainbow Lake	7	03	09	5-8	90	00	00	10	10	2.0	3	X	X	X	X	-	-
119 Whisker Lake	7	02	04	5,11	95	00	00	00	55	2.0	1	X	-	-	-	-	-
120 Blackjack Springs	11	01	00	10-11	99	00	00	00	50	1.0	4	X	-	-	-	-	-
121 Hercules Glades	12	02	42	10-11	50	02	00	10	34	2.0	1	-	X	X	-	-	-
122 Upper Buffalo	10	01	00	4,10	40	00	00	00	25	3.0	4	X	-	-	-	-	-
123 Caney Creek	14	04	09	5,10	10	00	00	00	01	3.0	4	-	X	X	-	-	-
124 Bristol Cliffs	4	02	00	11	90	00	00	00	75	2.0	3	-	-	-	X	-	-
125 Lye Brook	15	08	13	7-8	20	00	00	05	10	1.8	3	-	-	-	X	-	-
126 Great Gulf	5	40	25	7-8	60	00	00	05	01	2.8	3	X	X	-	X	-	-
127 Presidential-Dry River	20	23	36	7-9	23	00	00	05	01	2.3	3	X	X	-	X	-	-
128 Dolly Sods	10	35	26	7,10	28	00	00	05	10	2.8	3	X	-	-	X	-	-
129 Otter Creek	20	18	41	7-8	23	01	03	01	30	1.6	3	-	-	-	X	-	-
130 Beaver Creek	5	02	02	6-8	95	01	00	01	00	3.0	4	X	-	-	-	X	-
131 James River Face	9	05	25	7-8	80	01	00	00	40	2.0	4	X	X	-	-	-	-
132 Gee Creek	2	03	02	5-8	95	00	00	05	20	1.0	4	X	-	-	-	-	-
133 Joyce Kilmer-Slickrock	4	01	23	8-10	43	05	01	01	50	3.0	3	X	X	-	-	-	-
134 Joyce Kilmer-Slickrock	10	14	60	6-8	80	01	00	01	01	3.0	4	X	-	-	-	-	-
135 Cohutta	2	04	04	4-5	70	05	00	05	02	2.0	4	X	-	-	-	-	-

See footnotes at end of table 29, p.23

Table 29.—(con.)

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors: Day-users	With packstock	With outfitters	With outdoor education programs	Hunters	Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques: Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
136 Cohutta	32	17	66	6-8	30	02	00	02	20	3.0	3	X	X	-	-	-	-
137 Linville Gorge	8	45	28	---	66	00	00	01	10	3.0	3	X	-	-	X	-	-
138 Shining Rock	13	210	32	6-9	56	01	UK	00	26	2.0	3	-	-	-	X	-	-
139 Ellicott Rock[d]	0.3	10	06	6-10	45	00	00	00	20	2.5	1	X	X	-	-	-	-
140 Ellicott Rock	3	10	02	6-8	98	00	00	01	01	1.5	4	X	X	X	-	-	X
141 Sipsey	13	10	00	3,10	60	00	00	00	UK	2.0	1	X	X	-	-	-	-
142 Bradwell Bay	23	01	02	4,5,10-12	95	00	00	00	50	1.5	4	X	-	-	-	-	-
F.S. PRIMITIVE AREAS																	
143 Salmon Trinity Alps	35	128	61	6-9	10	08	00	00	02	6.0	3	X	-	-	X	-	-
144 Salmon Trinity Alps	253	50	300	6-8	03	05	02	01	10	4.0	3	X	-	X	-	-	-
145 High Sierra[d]	2	01	00	6-8	UK	00	00	00	10	UK	2	-	-	X	-	-	-
146 Salmon River Breaks	94	25	140	9-10	25	60	50	01	60	4.0	3	X	X	X	X	-	-
147 Salmon River Breaks	122	16	287	9-11	04	80	30	00	85	7.0	3	X	X	-	-	X	-
148 Idaho[d]	690	55	850	7-10	05	20	25	00	40	5.0	3	-	X	X	-	X	X
149 Idaho	242	88	344	6-8	05	06	75	01	07	5.0	3	-	X	-	X	-	X
150 Idaho	75	42	200	7-8	02	35	02	01	15	5.3	3	X	-	X	-	X	X
151 Spanish Peaks	63	16	128	7-10	67	12	01	01	30	2.0	3	X	-	X	-	-	-
152 Cloud Peak	137	73	105	6-8	78	20	01	05	01	4.0	3	-	X	X	-	-	-
153 Glacier	6	01	12	7-9,11	99	40	05	00	25	1.0	3	X	-	X	-	-	-
154 Popo Agie	71	47	110	7-8	01	11	31	25	01	5.0	3	-	X	X	X	-	-
155 High Unitas	74	64	100	7-8	20	30	00	01	00	2.5	3	-	X	X	-	-	-
156 High Uintas	163	218	328	7-8	30	12	05	02	01	2.5	3	-	X	-	-	-	-
157 Uncompahgre	69	53	65	6-8	90	01	05	01	02	3.5	3	X	-	X	-	-	X
158 Wilson Mountains	21	06	13	7-9	70	02	15	10	07	2.0	3	X	X	-	-	-	-
159 Wilson Mountains	10	06	05	7-8	38	05	05	01	15	2.0	3	X	X	X	X	-	-
160 Blue Range	175	04	150	6-10	50	30	05	00	70	3.0	3	X	-	-	-	-	-
161 Blue Range	37	01*	17	4-6	50	05	00	00	10	2.0	4	X	-	-	-	-	-
162 Gila	133	12	50	5,7	04	09	04	04	04	3.5	1	X	X	-	X	-	-
163 Aldo Leopold-Black Range	170	15	250	6-8	75	35	00	05	25	3.0	2	X	-	X	-	-	-
NPS WILDERNESS																	
164 Haleakala	19	27	30	---	44	04	01	00	-	3.0	3	X	-	X	X	-	-
165 Hawaii Volcanoes	123	12*	65	8	01	01	00	25	-	2.5	3	X	-	-	X	-	-
166 Lava Beds	28	01	18	3-4	95	00	00	00	-	2.0	3	X	-	X	-	-	-
167 Lassen Volcanic	79	38	140	6-8	65	02	00	00	-	1.5	3	-	X	-	X	-	-
168 Point Reyes	25	300	50	---	90	05	00	00	-	2.0	1	X	X	-	X	X	X
169 Pinnacles	13	168	16	4	100	00	00	00	-	---	1	X	-	-	-	-	-
170 Joshua Tree	430	12	16	4	95	00	00	00	-	2.0	2	X	-	X	-	-	-
171 Craters of the Moon	43	01*	15	5-6,9-10	80	01	00	00	-	2.0	4	X	-	-	-	-	-
172 Black Canyon of the Gunnison	11	02	00	5-8	70	00	00	00	-	2.0	3	X	X	-	-	-	-
173 Great Sand Dunes	33	76*	00	6-8	95	00	00	01	-	2.0	3	X	-	-	X	-	-
174 Mesa Verde	8	00	00	---	00	00	00	00	-	---	-	-	-	-	-	-	-
175 Petrified Forest	50	01	00	7-8	70	00	00	00	-	1.5	1	X	-	-	X	-	-
176 Organ Pipe Cactus	313	04	04	1-3	70	00	00	01	-	2.5	4	-	-	X	-	-	-
177 Saguaro	71	9*	70	2-3	80	01	01	01	-	2.0	1	-	-	X	-	-	-
178 Chiricahua	9	04	17	---	100	01	00	00	-	---	-	-	-	X	-	-	-

See footnotes at end of table 29, p.23

Table 29.—(con.)

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors					Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques					
					Day-users	With packstock	With outfitters	With outdoor education programs	Hunters			Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
179 Bandelier	23	00	54	5	52	00	08	02	-	1.8	3	-	-	-	X	-	-
180 Carlsbad Caverns	33	02	28	6-7	85	03	00	05	-	2.1	3	X	-	-	X	-	-
181 Guadalupe Mountains	47	14	45	---	60	01	00	01	-	2.6	3	X	-	X	X	-	-
182 Theodore Roosevelt	30	03	47	6-8	65	45	45	00	-	2.2	3	X	-	-	X	-	-
183 Badlands	64	03	13	6-8	80	01	00	00	-	2.0	3	X	-	-	-	-	-
184 Isle Royale	132	70	166	6-8	13	00	00	01	-	4.2	3	X	X	-	X	-	-
185 Buffalo National River	11	UK	00	3-5	70	02	00	05	-	2.0	4	X	-	-	-	X	-
186 Shenandoah	80	224*	324	7-8	70	01	00	01	-	2.0	1	X	X	X	X	-	X
187 Everglades	1297	58*	175	---	98	00	10	01	-	3.1	1	-	X	-	X	-	-
188 Gulf Islands	2	38	00	5-7	20	00	00	00	-	3.0	3	X	X	-	-	-	-
NPS PROPOSED WILDERNESS																	
189 Mount McKinley	1848	60*	20	6-8	75	10	10	10	-	3.0	3	-	X	-	X	-	-
190 Katmai	2603	02	07	7-8	03	00	01	00	-	4.0	2	X	-	-	X	-	-
191 Glacier Bay	2225	04*	10	6-9	10	00	10	01	-	5.0	2	-	X	-	-	-	-
192 North Cascades Complex	537	05	371	7-8	20	01	01	01	-	2.6	3	X	-	-	X	-	-
193 Olympic	861	214*	600	7-8	60	01	01	01	-	2.5	3	X	-	X	X	-	-
194 Mount Rainier	208	141	360	7-8	93	01	01	01	-	2.0	4	-	-	X	X	-	-
195 Crater Lake	127	14	100	7-8	90	01	00	00	-	1.8	3	-	-	X	X	-	-
196 Yosemite	647	344*	631	6-8	30	01	02	01	-	3.0	1	X	X	-	X	-	-
197 Sequoia-Kings Canyon	803	333*	710	7-8	15	02	02	03	-	4.2	3	X	X	-	X	-	-
198 Death Valley	1908	01	07	3-4	UK	01	01	02	-	3.0	3	-	X	-	-	-	-
199 Glacier	928	62*	675	7-8	80	01	01	01	-	2.3	3	X	X	-	X	X	-
200 Yellowstone	2033	143*	1000+	6-8	84	01	01	UK	-	2.2	1	-	-	-	X	-	-
201 Grand Teton[e]	123	75*	134	-	58	-	-	-	-	-	-	-	-	X	-	-	X
202 Dinosaur	206	71*	10	6-8	10	01	50	10	-	3.0	3	X	-	-	-	-	-
203 Rocky Mountain	240	221*	300	7-9	92	09	08	UK	-	1.7	1	X	X	-	X	-	-
204 Colorado	14	UK	05	4,10	98	05	00	00	-	1.0	1	X	-	-	-	-	-
205 Zion	121	25*	65	5-6	UK	01	00	01	-	2.5	3	-	X	X	X	-	-
206 Cedar Breaks	5	01	00	7-9	65	00	00	00	-	1.6	3	-	X	-	-	-	-
207 Bryce Canyon	21	01	40	5-8	20	00	00	00	-	2.0	3	-	-	-	X	-	-
208 Capitol Reef	180	01	15	3,5,6	75	00	00	00	-	2.0	3	X	X	-	X	X	-
209 Canyonlands	260	30*	198	6-8	10	01	01	02	-	1.5	2	X	-	-	X	-	-
210 Arches	62	05*	06	2-5	75	00	00	10	-	2.0	3	X	-	-	X	-	-
211 Cumberland Gap	12	05*	30	5	80	05	00	02	-	2.0	3	X	X	X	X	X	-
212 Great Smoky Mountains	391	240*	858	-	UK	05	01	01	-	2.3	3	X	X	-	X	-	-
F&WS WILDERNESS																	
213 San Juan Islands	0.4	21	00	7-8	90	00	UK	UK	02	2.0	3	X	-	-	-	-	-
214 Red Rocks Lakes	32	01*	00	7-10	100	00	00	00	01	0.0	4	X	X	X	-	X	-
215 Crab Orchard	4	02	00	5,9,10	100	02	00	10	20	0.0	3	X	-	-	-	-	-
216 Mingo	8	01*	00	4-6	100	00	00	10	00	0.0	-	X	-	-	-	-	-
217 Wichita Mountains	9	08	03	3	100	-	00	00	02	0.0	-	X	-	-	-	-	-
218 Lacassine	3	01	00	11-12	100	00	00	00	100	0.0	-	-	X	-	-	-	-
219 Breton	5	01*	00	7-9	100	00	00	00	00	0.0	-	X	-	-	-	-	-
220 Monomy	2	06*	00	6-9	99	00	00	01	00	2.0	-	X	-	-	-	-	-

See footnotes at end of table 29, p. 23

Table 29.—(con.)

	Acres in 1000's	Use (RVD's) in 1,000's[a]	Trail Miles	Heavy Use Season (months with ≥15% of total use)	Percent of Visitors					Mean length of stay (days)[b]	Experience of visitors[c]	Use-estimation techniques					
					Day-users	With packstock	With outfitters	With outdoor education programs	Hunters			Observations	Field tallies	Self-registration	Agency registration	Road counters	Trail counters
221 Great Swamp	4	09	05	-	10	00	00	02	01	0.0	4	X	X	-	-	X	-
222 Cape Romain	28	01*	03	-	98	00	00	00	01	2.0	4	X	-	-	-	-	-
223 Blackbeard Island	3	03*	05	7,10,12	100	-	-	00	30	0.0	3	X	-	-	-	-	-
224 Wolf Island	5	01	00	9	100	00	00	00	00	0.0	-	-	-	-	-	-	-
225 Okefenokee	344	39*	120	-	95	00	01	01	00	2.0	3	-	X	X	X	X	X
226 Cedar Keys	0.4	01	00	4-5	100	00	00	00	00	0.0	-	X	X	-	-	-	-
227 Chassahowitzka	23	34	00	-	95	-	10	-	01	0.0	-	X	X	X	X	-	-
228 Passage Key	0.1	05	00	6-9	100	-	-	-	-	0.0	-	X	-	-	-	-	-
229 J.N. "Ding" Darling	3	16	00	-	100	00	00	00	00	0.0	-	X	X	-	-	-	-
F&WS PROPOSED WILDERNESS																	
230 Aleutian Islands	1395	33*	00	7-8	75	00	05	UK	75	4.0	4	X	X	-	-	-	-
231 Nunivak	1109	20	00	6-8	60	00	01	00	30	7.0	2	-	X	-	-	-	-
232 Kenai	829	13*	20	5-9	35	05	03	19	10	5.0	3	X	-	-	-	-	-
233 Kenai Lakes	2	13	160	5-7	30	00	01	03	07	5.0	3	X	X	X	-	-	-
234 Hart Mountain	16	01*	00	7-10	80	01	00	05	50	2.0	3	X	X	X	X	-	-
235 Havasu	3	06*	00	6-8	100	01	-	-	00	0.0	4	X	X	-	-	-	-
236 Charles M. Russell	155	01*	00	9-11	80	10	05	00	80	2.0	4	X	X	-	-	-	-
237 Desert	1443	07*	00	-	98	01	00	UK	01	3.0	2	-	X	X	X	X	-
238 Kofa	571	09*	00	3	35	15	01	00	25	2.0	2	X	-	-	-	X	-
239 Cabeza Prieta	834	03	124	3-4	35	01	00	00	00	3.0	2	X	-	-	X	-	-
240 Missiquoi	2	03*	-	10-11	100	-	-	-	95	0.0	-	X	X	-	-	-	-
241 Parker River	3	20*	01	9-10	100	-	-	01	08	0.0	-	X	X	-	X	-	-
BLM PRIMITIVE AREAS																	
242 Chemise Mountain	4	01	04	6-8	50	00	00	UK	10	2.0	3	-	-	X	-	-	-
243 Humbug Spires	7	UK	00	5,9	95	05	00	00	20	2.5	2	X	-	-	-	-	-
244 Beartrap Canyon	3	03	00	6	90	02	01	00	05	2.0	3	X	-	-	-	-	-
245 Centennial Mountains	24	UK	00	8,9	35	55	80	00	20	4.0	1	X	-	-	-	-	-
246 Scab Creek	7	10	04	7,9,10	50	15	05	10	40	4.0	1	-	X	-	-	X	X
247 Powderhorn	40	05	70	7-10	40	20	05	05	40	3.0	3	X	X	X	-	-	-
248 Paria Canyon	28	11	35	4-6	01	01	02	00	00	4.0	3	X	-	X	X	-	-
249 Dark Canyon	57	05	300	4-6	01	01	01	08	01	5.0	2	X	-	-	X	-	-
250 Grand Gulch	24	10	100+	3-6	05	95	10	05	01	5.0	2	-	-	-	X	-	-
251 Paiute	35	01	12	4,5	60	00	00	00	60	2.0	4	X	-	-	-	-	-
252 Aravaipa Canyon	5	10	00	-	47	01	01	01	UK	1.3	3	-	X	X	X	-	X

[a] Annual use in 12-hour Recreation Visitor Days. (*)-denotes conversion from Visits or Overnight Stays.
[b] For overnight visitors (campers).
[c] (1)-beginners more common; (2)-experienced users more common; (3)-average experience; (4)-experience unknown
[d] Additional acreage managed by adjacent forest that did not return a questionnaire.
[e] No questionnaire returned. Selected data collected by telephone

Table 30.—Management problems

F.S. WILDERNESS	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								Boundary related problems
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	
1 Pasayten	-	FP	FP	-	FP	FP	MP	MP	FP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	-
2 Glacier Peak	-	MP	FP	-	FP	-	-	FP	-	-	FP	-	-	-	-	FP	FP	FP	FP	-	-
3 Glacier Peak	FP	FP	FP	FP	FP	FP	FP	FP	-	MP	FP	-	-	-	FP	-	-	-	FP	-	-
4 Alpine Lakes	MP	MP	MP	MP	MP	MP	FP	FP	-	FP	FP	-	-	-	FP	FP	MP	FP	FP	-	X
5 Alpine Lakes	FP	FP	MP	FP	FP	FP	-	FP	FP	FP	FP	-	FP	-	FP	FP	FP	-	FP	-	-
6 Goat Rocks	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	FP	-	FP	-	-	-	X
7 Goat Rocks	MP	MP	FP	MP	MP	MP	MP	MP	MP	MP	FP	FP	UK	FP	MP	FP	FP	FP	-	-	X
8 Mount Adams	FP	MP	FP	MP	MP	FP	-	FP	-	FP	MP	FP	-	FP	FP	FP	FP	-	FP	FP	-
9 Wenaha-Tucannon	-	FP	-	-	-	-	FP	MP	-	FP	MP	-	-	FP	MP	-	MP	-	-	-	X
10 Eagle Cap	-	MP	MP	MP	MP	FP	-	MP	FP	MP	MP	FP	FP	FP	FP	FP	FP	FP	-	-	-
11 Hells Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	FP	-	-	-
12 Hells Canyon	FP	MP	MP	FP	MP	MP	-	-	FP	-	-	-	-	-	-	MP	MP	-	-	-	X
13 Strawberry Mountain	FP	MP	MP	MP	MP	FP	-	FP	FP	FP	FP	FP	-	FP	FP	-	FP	-	-	-	X
14 Mount Hood	-	FP	FP	-	FP	FP	-	-	-	-	-	-	MP	-	-	FP	FP	-	FP	-	-
15 Mount Jefferson	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-	-
16 Mount Jefferson	-	FP	FP	MP	MP	MP	-	FP	FP	-	FP	FP	FP	-	FP	FP	MP	FP	-	-	X
17 Mount Jefferson	-	MP	MP	MP	MP	MP	-	-	-	FP	FP	FP	-	-	-	FP	-	-	-	-	X
18 Mount Washington	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	X
19 Mount Washington	-	FP	FP	-	-	-	-	FP	FP	-	FP	FP	-	-	FP	FP	-	-	-	-	-
20 Three Sisters	FP	MP	MP	FP	MP	MP	-	-	-	-	-	-	FP	-	-	FP	MP	-	-	-	X
21 Three Sisters	MP	MP	MP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	-	FP	FP	-	-	-	X
22 Diamond Peak	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	FP	FP	-	-	-	-	X
23 Diamond Peak	-	FP	FP	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24 Mountain Lake	-	-	FP	FP	-	FP	-	-	-	FP	-	-	-	-	FP	-	-	-	-	-	-
25 Gearhart Mountain	-	-	FP	FP	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
26 Wild Rogue	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	FP	FP	FP	FP	-	-	-
27 Kalmiopsis	-	FP	-	FP	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
28 Marble Mountain	FP	MP	FP	MP	MP	FP	-	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	FP	-	X
29 South Warner	-	-	-	FP	FP	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	-
30 Thousand Lakes	-	FP	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	FP	-	-	-	-	-
31 Caribou	FP	FP	FP	FP	FP	FP	-	-	-	FP	FP	-	-	FP	-	-	-	-	-	-	-
32 Yolla Bolly-Middle Eel	-	FP	FP	MP	FP	MP	MP	FP	FP	FP	FP	FP	-	-	FP	-	-	-	-	-	X
33 Desolation	MP	MP	MP	MP	FP	MP	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	-	FP	-	-
34 Mokelumne	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	FP	FP	-	FP	-	-
35 Mokelumne	-	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	-	-	FP	FP	-	-	-	-	-
36 Emigrant	FP	MP	FP	FP	MP	FP	FP	MP	-	MP	MP	-	MP	-	MP	FP	MP	FP	-	-	X
37 Hoover	-	MP	FP	FP	MP	FP	FP	FP	FP	FP	FP	FP	FP	-	FP	-	MP	FP	-	-	-
38 Hoover	-	MP	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	-	FP	-	FP	-	X
39 Minarets	FP	FP	FP	-	FP	MP	FP	-	-	FP	-	-	-	-	FP	FP	FP	-	-	-	-
40 Minarets	-	MP	MP	-	FP	FP	-	MP	FP	-	FP	FP	-	FP	FP	FP	MP	FP	FP	-	X
41 Kaiser	-	MP	MP	FP	FP	FP	-	MP	MP	FP	-	FP	-	-	FP	-	FP	-	-	-	-
42 John Muir	MP	MP	MP	MP	MP	FP	MP	MP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	FP	-	-
43 John Muir	FP	MP	FP	FP	FP	-	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	FP	-	MP	-	X
44 Golden Trout	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45 Golden Trout	-	-	-	-	-	-	-	-	FP	FP	-	FP	FP	-	-	-	-	FP	FP	-	X

See footnotes at end of table 30, p. 29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
46 Domeland	FP	FP	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-
47 Ventana	FP	MP	FP	FP	FP	FP	FP	-	-	-	-	-	FP	-	FP	FP	FP	FP	-	-	X
48 Santa Lucia	-	-	-	FP	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-	-
49 San Rafael	FP	MP	-	-	MP	-	-	FP	-	-	-	-	-	-	FP	FP	FP	-	FP	-	-
50 San Gabriel	FP	FP	FP	MP	FP	-	-	-	-	-	-	-	-	FP	MP	FP	MP	FP	MP	MP	-
51 Cucamonga	MP	MP	MP	FP	FP	FP	-	-	-	-	-	-	-	-	MP	-	-	-	MP	MP	-
52 San Gorgonio	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-
53 San Jacinto	-	-	-	FP	FP	FP	-	-	-	-	-	-	-	FP	FP	MP	MP	-	-	-	-
54 Aqua Tibia	FP	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
55 Jarbidge	FP	FP	FP	-	-	-	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	-	X
56 Selway-Bitterroot	FP	FP	FP	-	FP	FP	MP	MP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	FP	-	-
57 Selway-Bitterroot	-	MP	FP	MP	MP	FP	-	MP	FP	MP	MP	FP	FP	-	FP	FP	FP	FP	FP	-	X
58 Selway-Bitterroot	MP	MP	MP	FP	MP	MP	MP	MP	MP	MP	MP	MP	FP	-	MP	FP	FP	FP	FP	-	X
59 Selway-Bitterroot	-	FP	-	FP	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-
60 Sawtooth	-	-	-	FP	MP	FP	-	FP	-	FP	-	-	-	-	-	FP	FP	-	-	-	X
61 Gospel Hump	-	FP	FP	-	-	FP	FP	FP	FP	FP	FP	FP	-	-	FP	-	-	FP	-	-	X
62 Cabinet Mountains	-	FP	FP	FP	MP	FP	-	FP	FP	-	-	FP	FP	-	FP	FP	FP	FP	-	-	X
63 Mission Mountains	FP	MP	FP	FP	MP	FP	FP	FP	-	FP	FP	-	-	-	FP	-	FP	-	-	-	X
64 Great Bear	-	-	-	-	FP	FP	-	-	-	MP	MP	FP	FP	-	FP	-	-	FP	-	-	X
65 Bob Marshall	FP	FP	FP	-	-	-	FP	FP	FP	MP	FP	FP	-	-	MP	FP	FP	FP	-	-	-
66 Bob Marshall	-	FP	-	FP	FP	-	-	FP	-	FP	FP	FP	-	-	FP	FP	FP	-	-	-	-
67 Scapegoat	-	FP	-	FP	FP	-	-	FP	-	FP	FP	-	-	-	FP	-	FP	FP	-	-	X
68 Scapegoat	-	FP	FP	-	-	-	FP	FP	FP	FP	FP	-	FP	-	FP	FP	-	-	-	-	-
69 Scapegoat	-	-	-	FP	-	-	FP	FP	-	FP	FP	-	-	-	FP	-	-	-	-	-	-
70 Gates of the Mountain	-	FP	-	-	FP	-	-	FP	-	FP	FP	-	-	-	FP	-	-	-	-	-	-
71 Welcome Creek	FP	MP	FP	FP	MP	FP	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	X
72 Anaconda-Pintler	-	FP	FP	FP	FP	FP	-	FP	-	FP	FP	FP	-	-	-	-	-	-	-	-	-
73 Anaconda-Pintler	-	MP	MP	FP	FP	-	-	FP	FP	FP	FP	-	-	FP	-	FP	FP	-	FP	-	-
74 Anaconda-Pintler	FP	MP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	FP	FP	-	-	-	-	X
75 Absaroka-Beartooth	FP	MP	FP	FP	FP	FP	FP	MP	MP	MP	MP	MP	FP	FP	MP	MP	FP	FP	-	-	X
76 Absaroka-Beartooth	-	MP	FP	-	FP	FP	-	MP	-	FP	FP	-	-	-	FP	MP	MP	-	FP	-	X
77 North Absaroka	-	FP	FP	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	FP	-	-	-	-	-	X
78 Washakie	-	-	-	-	FP	-	-	-	-	FP	FP	FP	FP	-	FP	-	FP	-	-	-	-
79 Fitzpatrick	FP	FP	MP	FP	FP	FP	FP	FP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	-	-	-
80 Teton	-	-	-	-	-	-	MP	FP	FP	MP	FP	FP	-	-	-	-	FP	-	-	-	-
81 Bridger	MP	MP	MP	MP	FP	FP	FP	FP	FP	MP	FP	FP	MP	-	MP	FP	MP	FP	-	FP	X
82 Savage Run	-	-	-	FP	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-
83 Lone Peak	-	FP	-	MP	FP	-	-	-	-	-	-	-	-	MP	FP	FP	FP	-	-	-	X
84 Lone Peak	-	FP	FP	FP	FP	FP	-	FP	-	FP	-	-	FP	FP	FP	FP	FP	-	FP	-	-
85 Mount Zirkel	FP	FP	FP	-	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	FP	FP	-	-
86 Rawah	-	MP	FP	FP	FP	FP	FP	FP	-	FP	FP	-	-	-	-	-	MP	FP	FP	-	-
87 Flat Tops	FP	-	MP	FP	-	FP	-	FP	MP	FP	FP	FP	MP	-	MP	FP	-	-	-	-	X
88 Flat Tops	FP	FP	FP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	MP	FP	FP	FP	-	-	X
89 Indian Peaks	FP	MP	MP	FP	MP	MP	-	-	-	-	-	-	FP	FP	-	FP	MP	FP	FP	-	-
90 Eagles Nest	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	FP	FP	FP	MP	MP	FP	FP	FP	X

See footnotes at end of table 30, p. 29

Table 30.—Management problems

F.S. WILDERNESS	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								Boundary related problems
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	
1 Pasayten	-	FP	FP	-	FP	FP	MP	MP	FP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	-
2 Glacier Peak	-	MP	FP	-	FP	-	-	FP	-	-	FP	-	-	-	-	FP	FP	FP	FP	-	-
3 Glacier Peak	FP	FP	FP	FP	FP	FP	FP	FP	-	MP	FP	-	-	-	FP	-	-	-	FP	-	-
4 Alpine Lakes	MP	MP	MP	MP	MP	MP	FP	FP	-	FP	FP	-	-	-	FP	FP	MP	FP	FP	-	X
5 Alpine Lakes	FP	FP	MP	FP	FP	FP	-	FP	FP	FP	FP	-	FP	-	FP	FP	FP	-	FP	-	-
6 Goat Rocks	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	FP	-	FP	-	-	-	X
7 Goat Rocks	MP	MP	FP	MP	MP	MP	MP	MP	MP	MP	FP	FP	UK	FP	MP	FP	FP	FP	-	-	X
8 Mount Adams	FP	MP	FP	MP	MP	FP	-	FP	-	FP	MP	FP	-	FP	FP	FP	FP	-	FP	FP	-
9 Wenaha-Tucannon	-	FP	-	-	-	-	FP	MP	-	FP	MP	-	-	FP	MP	-	MP	-	-	-	X
10 Eagle Cap	-	MP	MP	MP	MP	FP	-	MP	FP	MP	MP	FP	FP	FP	FP	FP	FP	FP	-	-	-
11 Hells Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	FP	-	-	-
12 Hells Canyon	FP	MP	MP	FP	MP	MP	-	-	FP	-	-	-	-	-	-	MP	MP	-	-	-	X
13 Strawberry Mountain	FP	MP	MP	MP	MP	FP	-	FP	FP	FP	FP	FP	-	FP	FP	-	FP	-	-	-	X
14 Mount Hood	-	FP	FP	-	FP	FP	-	-	-	-	-	-	MP	-	-	FP	FP	-	FP	-	-
15 Mount Jefferson	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-	-
16 Mount Jefferson	-	FP	FP	MP	MP	MP	-	FP	FP	-	FP	FP	FP	-	FP	FP	MP	FP	-	-	X
17 Mount Jefferson	-	MP	MP	MP	MP	MP	-	-	-	FP	FP	FP	-	-	-	FP	-	-	-	-	X
18 Mount Washington	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	X
19 Mount Washington	-	FP	FP	-	-	-	-	FP	FP	-	FP	FP	-	-	FP	FP	-	-	-	-	-
20 Three Sisters	FP	MP	MP	FP	MP	MP	-	-	-	-	-	-	FP	-	-	FP	MP	-	-	-	X
21 Three Sisters	MP	MP	MP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	-	FP	FP	-	-	-	X
22 Diamond Peak	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	FP	FP	-	-	-	-	X
23 Diamond Peak	-	FP	FP	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24 Mountain Lake	-	-	FP	FP	-	FP	-	-	-	FP	-	-	-	-	FP	-	-	-	-	-	-
25 Gearhart Mountain	-	-	FP	FP	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
26 Wild Rogue	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	FP	FP	FP	FP	-	-	-
27 Kalmiopsis	-	FP	-	FP	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
28 Marble Mountain	FP	MP	FP	MP	MP	FP	-	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	FP	-	X
29 South Warner	-	-	-	FP	FP	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	-
30 Thousand Lakes	-	FP	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	FP	-	-	-	-	-
31 Caribou	FP	FP	FP	FP	FP	FP	-	-	-	FP	FP	-	-	FP	-	-	-	-	-	-	-
32 Yolla Bolly-Middle Eel	-	FP	FP	MP	FP	MP	MP	FP	FP	FP	FP	FP	-	-	FP	-	-	-	-	-	X
33 Desolation	MP	MP	MP	MP	FP	MP	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	-	FP	-	-
34 Mokelumne	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	FP	FP	-	FP	-	-
35 Mokelumne	-	FP	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	-	-	FP	FP	-	-	-	-	-
36 Emigrant	FP	MP	FP	FP	MP	FP	FP	MP	-	MP	MP	-	MP	-	MP	FP	MP	FP	-	-	X
37 Hoover	-	MP	FP	FP	MP	FP	FP	FP	FP	FP	FP	FP	FP	-	FP	-	MP	FP	-	-	-
38 Hoover	-	MP	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	-	FP	-	FP	-	X
39 Minarets	FP	FP	FP	-	FP	MP	FP	-	-	FP	-	-	-	-	FP	FP	FP	-	-	-	-
40 Minarets	-	MP	MP	-	FP	FP	-	MP	FP	-	FP	FP	-	FP	FP	FP	MP	FP	FP	-	X
41 Kaiser	-	MP	MP	FP	FP	FP	-	MP	MP	FP	-	FP	-	-	FP	-	FP	-	-	-	-
42 John Muir	MP	MP	MP	MP	MP	FP	MP	MP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	FP	-	-
43 John Muir	FP	MP	FP	FP	FP	-	FP	FP	FP	FP	-	FP	FP	FP	FP	FP	FP	-	MP	-	X
44 Golden Trout	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45 Golden Trout	-	-	-	-	-	-	-	-	FP	FP	-	FP	FP	-	-	-	-	FP	FP	-	X

See footnotes at end of table 30, p. 29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
46 Domeland	FP	FP	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-
47 Ventana	FP	MP	FP	FP	FP	FP	FP	-	-	-	-	-	FP	-	FP	FP	FP	FP	-	-	X
48 Santa Lucia	-	-	-	FP	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-	-
49 San Rafael	FP	MP	-	-	MP	-	-	FP	-	-	-	-	-	-	FP	FP	FP	-	FP	-	-
50 San Gabriel	FP	FP	FP	MP	FP	-	-	-	-	-	-	-	-	FP	MP	FP	MP	FP	MP	MP	-
51 Cucamonga	MP	MP	MP	FP	FP	FP	-	-	-	-	-	-	-	-	MP	-	-	-	MP	MP	-
52 San Gorgonio	-	FP	FP	-	FP	FP	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-
53 San Jacinto	-	-	-	FP	FP	FP	-	-	-	-	-	-	-	FP	FP	MP	MP	-	-	-	-
54 Aqua Tibia	FP	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
55 Jarbidge	FP	FP	FP	-	-	-	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	-	X
56 Selway-Bitterroot	FP	FP	FP	-	FP	FP	MP	MP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	FP	-	-
57 Selway-Bitterroot	-	MP	FP	MP	MP	FP	-	MP	FP	MP	MP	FP	FP	-	FP	FP	FP	FP	FP	-	X
58 Selway-Bitterroot	MP	MP	MP	FP	MP	MP	MP	MP	MP	MP	MP	MP	FP	-	MP	FP	FP	FP	FP	-	X
59 Selway-Bitterroot	-	FP	-	FP	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-
60 Sawtooth	-	-	-	FP	MP	FP	-	FP	-	FP	-	-	-	-	-	FP	FP	-	-	-	X
61 Gospel Hump	-	FP	FP	-	-	FP	FP	FP	FP	FP	FP	FP	-	-	FP	-	-	FP	-	-	X
62 Cabinet Mountains	-	FP	FP	FP	MP	FP	-	FP	FP	-	-	FP	FP	-	FP	FP	FP	FP	-	-	X
63 Mission Mountains	FP	MP	FP	FP	MP	FP	FP	FP	-	FP	FP	-	-	-	FP	-	FP	-	-	-	X
64 Great Bear	-	-	-	-	FP	FP	-	-	-	MP	MP	FP	FP	-	FP	-	-	FP	-	-	X
65 Bob Marshall	FP	FP	FP	-	-	-	FP	FP	FP	MP	FP	FP	-	-	MP	FP	FP	FP	-	-	-
66 Bob Marshall	-	FP	-	FP	FP	-	-	FP	-	FP	FP	FP	-	-	FP	FP	FP	-	-	-	-
67 Scapegoat	-	FP	-	FP	FP	-	-	FP	-	FP	FP	-	-	-	FP	-	FP	FP	-	-	X
68 Scapegoat	-	FP	FP	-	-	-	FP	FP	FP	FP	FP	-	FP	-	FP	FP	-	-	-	-	-
69 Scapegoat	-	-	-	FP	-	-	FP	FP	-	FP	FP	-	-	-	FP	-	-	-	-	-	-
70 Gates of the Mountain	-	FP	-	-	FP	-	-	FP	-	FP	FP	-	-	-	FP	-	-	-	-	-	-
71 Welcome Creek	FP	MP	FP	FP	MP	FP	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	X
72 Anaconda-Pintler	-	FP	FP	FP	FP	FP	-	FP	-	FP	FP	FP	-	-	-	-	-	-	-	-	-
73 Anaconda-Pintler	-	MP	MP	FP	FP	-	-	FP	FP	FP	FP	-	-	FP	-	FP	FP	-	FP	-	-
74 Anaconda-Pintler	FP	MP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	FP	FP	-	-	-	-	X
75 Absaroka-Beartooth	FP	MP	FP	FP	FP	FP	FP	MP	MP	MP	MP	MP	FP	FP	MP	MP	FP	FP	-	-	X
76 Absaroka-Beartooth	-	MP	FP	-	FP	FP	-	MP	-	FP	FP	-	-	-	FP	MP	MP	-	FP	-	X
77 North Absaroka	-	FP	FP	-	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	FP	-	-	-	-	-	X
78 Washakie	-	-	-	-	FP	-	-	-	-	FP	FP	FP	FP	-	FP	-	FP	-	-	-	-
79 Fitzpatrick	FP	FP	MP	FP	FP	FP	FP	FP	FP	MP	MP	FP	-	-	FP	FP	FP	FP	-	-	-
80 Teton	-	-	-	-	-	-	MP	FP	FP	MP	FP	FP	-	-	-	-	FP	-	-	-	-
81 Bridger	MP	MP	MP	MP	FP	FP	FP	FP	FP	MP	FP	FP	MP	-	MP	FP	MP	FP	-	FP	X
82 Savage Run	-	-	-	FP	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-
83 Lone Peak	-	FP	-	MP	FP	-	-	-	-	-	-	-	-	MP	FP	FP	FP	-	-	-	X
84 Lone Peak	-	FP	FP	FP	FP	FP	-	FP	-	FP	-	-	FP	FP	FP	FP	FP	-	FP	-	-
85 Mount Zirkel	FP	FP	FP	-	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	FP	FP	-	-
86 Rawah	-	MP	FP	FP	FP	FP	FP	FP	-	FP	FP	-	-	-	-	-	MP	FP	FP	-	-
87 Flat Tops	FP	-	MP	FP	-	FP	-	FP	MP	FP	FP	FP	MP	-	MP	FP	-	-	-	-	X
88 Flat Tops	FP	FP	FP	MP	MP	MP	FP	FP	FP	FP	FP	FP	-	-	MP	FP	FP	FP	-	-	X
89 Indian Peaks	FP	MP	MP	FP	MP	MP	-	-	-	-	-	-	FP	FP	-	FP	MP	FP	FP	-	-
90 Eagles Nest	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	FP	FP	FP	MP	MP	FP	FP	FP	X

See footnotes at end of table 30, p. 29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
91 Maroon Bells-Snowmass	-	MP	MP	MP	MP	MP	-	FP	-	FP	-	-	-	-	FP	FP	MP	FP	-	-	X
92 Hunter Fryingpan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
93 West Elk	-	FP	FP	-	FP	FP	FP	FP	FP	FP	FP	FP	-	FP	FP	FP	-	-	-	-	-
94 La Garita	FP	MP	MP	-	FP	FP	FP	MP	-	MP	FP	-	-	FP	MP	FP	FP	FP	-	-	-
95 Weminuche	-	FP	-	FP	FP	FP	FP	MP	-	FP	FP	-	FP	-	FP	FP	FP	FP	-	-	X
96 Weminuche	FP	FP	FP	-	FP	FP	-	MP	MP	FP	FP	FP	FP	-	FP	FP	MP	FP	-	-	-
97 Sycamore Canyon	-	FP	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-
98 Sycamore Canyon	-	FP	MP	FP	-	-	-	FP	-	-	-	-	-	FP	FP	FP	-	-	-	-	-
99 Sycamore Canyon	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	FP	FP	-	-	-	MP	-	-
100 Pine Mountain	FP	FP	-	FP	FP	-	FP	-	-	FP	-	-	-	FP	-	FP	-	FP	-	-	-
101 Mazatzal	MP	MP	-	MP	MP	MP	MP	MP	MP	MP	MP	MP	-	FP	-	-	-	-	-	-	X
102 Sierra Ancha	-	FP	-	-	FP	-	FP	MP	-	MP	MP	-	-	-	FP	FP	FP	-	-	-	X
103 Superstition	MP	MP	-	MP	MP	-	MP	MP	-	MP	MP	-	-	MP	MP	MP	MP	MP	MP	MP	-
104 Mount Baldy	-	FP	-	FP	FP	-	-	-	-	FP	-	-	-	-	FP	-	FP	MP	-	-	X
105 Galiuro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
106 Pusch Ridge	FP	-	-	FP	-	-	-	-	-	-	-	-	MP	-	FP	FP	-	FP	FP	FP	X
107 Chiricahua	-	FP	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
108 Wheeler Peak	FP	MP	MP	FP	MP	MP	FP	MP	FP	FP	MP	FP	-	-	FP	-	-	-	-	-	X
109 San Pedro Parks	-	FP	FP	MP	FP	FP	-	FP	-	FP	FP	-	-	-	FP	FP	-	-	-	-	-
110 Chama River Canyon	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
111 Pecos	FP	MP	MP	FP	MP	MP	FP	FP	FP	FP	FP	FP	FP	MP	MP	FP	FP	FP	FP	-	-
112 Pecos	MP	MP	MP	MP	MP	MP	FP	FP	FP	MP	FP	MP	MP	FP	MP	FP	MP	FP	MP	FP	-
113 Manzano Mountains	FP	MP	-	FP	MP	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	X
114 Sandia Mountains	FP	FP	MP	MP	FP	MP	-	-	-	FP	-	FP	MP	FP	MP	FP	FP	MP	FP	-	-
115 Gila	-	-	-	-	FP	-	-	FP	-	-	FP	-	-	-	FP	FP	FP	-	-	-	-
116 White Mountain	-	-	-	FP	-	FP	-	-	-	FP	-	FP	-	-	FP	-	-	FP	FP	-	X
117 Boundary Waters Canoe Area	-	FP	-	-	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	MP	-	X
118 Rainbow Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119 Whisker Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	FP	-	-	-	-	X
120 Blackjack Springs	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-	FP	-	-	FP	-	-
121 Hercules Glades	-	FP	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-
122 Upper Buffalo	-	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
123 Caney Creek	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
124 Bristol Cliffs	-	-	FP	FP	-	FP	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	X
125 Lye Brook	FP	FP	FP	FP	FP	MP	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-	X
126 Great Gulf	MP	MP	MP	MP	MP	MP	-	-	-	-	-	-	-	-	FP	-	-	-	FP	-	-
127 Presidential-Dry River	MP	MP	MP	MP	MP	MP	-	-	-	-	-	-	-	FP	FP	-	-	-	FP	-	-
128 Dolly Sods	-	FP	-	MP	FP	-	-	-	-	-	-	-	FP	FP	FP	FP	FP	FP	-	-	X
129 Otter Creek	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	FP	-	FP	-	-	-	FP	-	X
130 Beaver Creek	-	FP	FP	-	-	FP	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	X
131 James River Face	FP	FP	-	MP	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	-	FP	-	-
132 Gee Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	UK	FP	FP	-	-	-	-	-
133 Joyce Kilmer-Slickrock	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	FP	FP	-	-	-	-	-
134 Joyce Kilmer-Slickrock	-	FP	-	FP	FP	FP	-	-	-	-	-	-	-	-	FP	-	FP	FP	FP	-	X
135 Cohutta	FP	-	-	FP	-	-	FP	-	-	FP	-	-	-	-	FP	-	-	-	FP	-	-

See footnotes at end of table 30, p.29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
136 Cohutta	-	-	-	-	FP	FP	-	-	-	-	-	-	-	-	FP	FP	FP	-	FP	-	-
137 Linville Gorge	-	MP	MP	FP	FP	FP	-	-	-	-	-	-	-	-	MP	MP	FP	FP	FP	-	-
138 Shining Rock	MP	FP	MP	MP	-	-		-	-		-	-	FP	-	FP	-	FP	-	FP	-	-
139 Ellicott Rock	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
140 Ellicott Rock	FP	MP	FP	FP	-	-	-	-	-	-	-	-	FP	-	FP	FP	FP	-	FP	-	-
141 Sipsey	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	MP	FP	FP	FP	-	-	-
142 Bradwell Bay	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
F.S. PRIMITIVE AREAS																					
143 Salmon Trinity Alps	FP	FP	FP	FP	FP	FP	-	FP	-	FP	FP	FP	-	-	-	FP	FP	FP	-	-	-
144 Salmon Trinity Alps	-	FP	FP	FP	MP	FP	-	FP	FP	FP	FP	-	-	FP	MP	FP	FP	-	FP	FP	-
145 High Sierra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
146 Salmon River Breaks	FP	FP	FP	MP	MP	MP	FP	FP	FP	MP	MP	MP	-	-	FP	FP	-	-	-	-	-
147 Salmon River Breaks	FP	FP	MP	MP	FP	FP	FP	FP	FP	MP	FP	FP	FP	-	MP	FP	FP	FP	-	-	X
148 Idaho	-	FP	FP	-	FP	FP	-	-	-	FP	FP	FP	MP	-	FP	FP	-	-	-	-	
149 Idaho	-	FP	-	-	FP	FP	-	FP	FP	-	FP	FP	-	FP	FP	FP	FP	FP	-	-	-
150 Idaho	-	FP	-	FP	FP	FP	FP	MP	FP	FP	FP	-	-	-	FP	FP	-	-	-	-	-
151 Spanish Peaks	FP	MP	MP	FP	FP	FP	FP	FP	FP	FP	FP	FP	-	-	FP	FP	FP	-	-	-	X
152 Cloud Peak	FP	MP	MP	-	FP	FP	-	FP	FP	-	FP	FP	-	-	FP	MP	FP	FP	-	-	-
153 Glacier	-	-	-	FP	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-
154 Popo Agie	FP	MP	FP	MP	MP	FP	FP	MP	FP	MP	MP	-	-	-	MP	MP	MP	FP	-	-	-
155 High Unitas	FP	FP	FP	FP	FP	-	-	FP	-	FP	MP	-	-	-	FP	FP	FP	-	FP	-	-
156 High Uintas	-	MP	MP	FP	MP	-	-	-	FP	MP	FP	FP	-	FP	MP	FP	MP	FP	-	-	X
157 Uncompahgre	FP	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	X
158 Wilson Mountains	-	FP	FP	FP	-	-	-	-	-	FP	-	-	-	-	-	FP	-	-	-	-	-
159 Wilson Mountains	-	FP	FP	FP	FP	FP	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-
160 Blue Range	FP	FP	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
161 Blue Range	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
162 Gila	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
163 Aldo Leopold-Black Range	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	X
NPS WILDERNESS																					
164 Haleakala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
165 Hawaii Volcanoes	-	-	-	FP	-	-	-	-	-	FP	-	-	FP	-	FP	-	FP	-	FP	-	X
166 Lava Beds	-	FP	-	-	FP	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	X
167 Lassen Volcanic	FP	FP	FP	-	FP	FP	FP	-	-	FP	-	-	-	FP	FP	-	FP	FP	-	-	X
168 Point Reyes	MP	MP	FP	MP	MP	FP	MP	FP	FP	MP	FP	FP	FP	FP	FP	FP	-	-	FP	-	-
169 Pinnacles	-	-	MP	-	-	MP	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	X
170 Joshua Tree	FP	-	-	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	FP		X
171 Craters of the Moon	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
172 Black Canyon of the Gunnison	-	MP	MP	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	MP	-	-	-	-
173 Great Sand Dunes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	X
174 Mesa Verde	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
175 Petrified Forest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
176 Organ Pipe Cactus	-	-	-	FP	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	X
177 Saguaro	-	-	-	FP	FP	-	-	-	-	FP	FP	-	-	-	FP	FP	-	-	FP	-	
178 Chiricahua	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

See footnotes at end of table 30, p. 29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
179 Bandelier	MP	FP	FP	MP	FP	FP	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-	X
180 Carlsbad Caverns	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
181 Guadalupe Mountains	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-
182 Theodore Roosevelt	-	-	-	FP	-	-	-	FP	-	-	FP	-	-	-	FP	-	-	-	-	-	-
183 Badlands	-	FP	-	-	FP	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	X
184 Isle Royale	FP	MP	FP	FP	MP	-	-	-	-	-	-	-	FP	FP	-	-	FP	FP	FP	-	-
185 Buffalo National River	-	FP	FP	FP	FP	FP	-	-	-	-	-	-	-	-	FP	-	-	-	FP	-	-
186 Shenandoah	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	FP	UK	MP	-	FP	-	-	-	-
187 Everglades	FP	MP	-	FP	MP	-	-	-	-	-	-	-	FP	-	FP	FP	FP	MP	-	-	X
188 Gulf Islands	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	MP	-	-	-	-	-	-
NPS PROPOSED WILDERNESS																					
189 Mount McKinley	FP	FP	FP	FP	-	FP	FP	FP	-	FP	FP	-	MP	-	-	-	-	-	-	-	-
190 Katmai	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
191 Glacier Bay	FP	-	-	FP	-	-	-	-	-	-	-	-	MP	-	-	FP	FP	FP	-	-	-
192 North Cascades Complex	-	FP	FP	-	FP	FP	-	FP	-	-	FP	-	FP	-	-	-	-	-	-	-	-
193 Olympic	MP	MP	MP	MP	MP	MP	FP	FP	FP	-	-	-	FP	-	FP	FP	FP	-	FP	-	X
194 Mount Rainier	FP	FP	-	FP	FP	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	FP	-	-
195 Crater Lake	-	FP	FP	FP	FP	FP	-	-	FP	-	-	FP	-	-	FP	FP	-	FP	-	-	-
196 Yosemite	-	MP	FP	MP	MP	FP	-	FP	-	MP	FP	FP	MP	FP	FP	FP	FP	FP	-	-	-
197 Sequoia-Kings Canyon	MP	MP	FP	MP	MP	FP	FP	FP	FP	FP	FP	FP	FP	-	MP	FP	FP	FP	FP	-	-
198 Death Valley	FP	FP	-	-	FP	-	-	-	-	FP	FP	-	MP	-	FP	FP	-	-	-	-	-
199 Glacier	FP	FP	FP	FP	FP	-	FP	FP	-	-	-	-	MP	-	-	FP	FP	-	FP	-	-
200 Yellowstone	-	MP	FP	FP	MP	FP	-	MP	-	FP	FP	-	FP	-	FP	FP	FP	FP	-	-	-
201 Grand Teton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202 Dinosaur	-	MP	FP	-	MP	FP	-	-	-	-	-	-	FP	-	FP	FP	FP	-	-	-	-
203 Rocky Mountain	FP	FP	FP	FP	FP	FP	-	-	-	-	-	-	FP	-	-	-	-	FP	-	-	-
204 Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
205 Zion	-	FP	FP	FP	MP	FP	-	-	-	-	-	-	FP	MP	MP	FP	FP	FP	FP	-	-
206 Cedar Breaks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207 Bryce Canyon	-	FP	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
208 Capitol Reef	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-
209 Canyonlands	-	-	-	FP	FP	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	-	-	-
210 Arches	FP	-	-	MP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
211 Cumberland Gap	FP	MP	-	FP	MP	-	FP	FP	-	FP	FP	-	-	-	MP	-	FP	FP	FP	-	-
212 Great Smoky Mountains	FP	MP	-	MP	MP	-	FP	FP	-	MP	FP	-	FP	-	MP	FP	FP	FP	FP	-	-
F&WS WILDERNESS																					
213 San Juan Islands	FP	FP	-	-	FP	-	-	-	-	-	-	-	FP	-	-	-	FP	-	-	-	X
214 Red Rocks Lakes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
215 Crab Orchard	FP	-	-	MP	-	FP	-	-	-	FP	-	-	-	-	MP	FP	-	-	MP	-	-
216 Mingo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
217 Wichita Mountains	FP	-	FP	FP	-	FP	-	-	-	-	-	-	-	-	FP	-	FP	FP	FP	-	-
218 Lacassine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
219 Breton	-	-	-	-	-	-	-	-	-	-	-	-	MP	-	-	-	-	-	-	-	X
220 Monomy	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	FP	-	FP	-	-	-	-

See footnotes at end of table 30, p. 29

Table 30.—(con.)

	Recreation-caused resource problems[a]												Other recreation-caused impacts[a]								
	Human-caused vegetation impact			Human-caused soil impact			Packstock-caused vegetation impact			Packstock-caused soil impact											
	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	Trails	Campsites	Waterbodies	On wildlife	Water pollution	Litter	Human Waste	Crowding	Conflicts between users	Trailhead vandalism	Theft within area	Boundary related problems
221 Great Swamp	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	-	FP	FP	FP	-	FP	-	X
222 Cape Romain	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-	X
223 Blackbeard Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
224 Wolf Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
225 Okefenokee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-
226 Cedar Keys	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-
227 Chassahowitzka	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-
228 Passage Key	-	-	-	-	-	-	-	-	-	-	-	-	MP	-	-	-	-	-	-	-	-
229 J.N. "Ding" Darling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F&WS PROPOSED WILDERNESS																					
230 Aleutian Islands	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	FP	FP	FP	-	-	-	-	-
231 Nunivak	-	-	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
232 Kenai	FP	-	-	FP	-	-	FP	FP	FP	FP	FP	FP	FP	-	FP	FP	-	-	-	-	X
233 Kenai Lakes	MP	FP	FP	MP	MP	FP	-	-	-	-	-	-	-	-	FP	FP	FP	-	-	-	X
234 Hart Mountain	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
235 Havasu	FP	-	MP	-	-	FP	-	-	-	FP	-	-	MP	-	MP	-	-	-	-	-	-
236 Charles M. Russell	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	FP	-	-	-
237 Desert	-	-	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-	-	-	-	-
238 Kofa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	FP	-	-	-
239 Cabeza Prieta	FP	FP	-	FP	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
240 Missiquoi	-	-	FP	-	-	-	-	-	-	-	-	-	MP	-	-	-	MP	-	-	-	-
241 Parker River	FP	-	-	FP	-	-	-	-	-	-	-	-	FP	-	FP	FP	MP	FP	MP	-	X
BLM PRIMITIVE AREAS																					
242 Chamise Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
243 Humbug Spires	-	FP	FP	MP	FP	FP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
244 Beartrap Canyon	-	FP	-	FP	FP	FP	-	-	-	-	-	-	-	-	FP	-	-	-	-	-	-
245 Centennial Mountains	MP	MP	MP	MP	MP	MP	-	-	-	-	-	-	-	-	FP	-	-	FP	-	-	-
246 Scab Creek	-	-	-	MP	-	-	-	-	-	MP	-	-	-	-	-	-	-	-	-	-	X
247 Powderhorn	-	FP	FP	-	FP	FP	-	FP	FP	FP	FP	FP	FP	-	-	-	FP	-	-	-	-
248 Paria Canyon	-	FP	-	-	-	-	-	-	-	-	-	-	-	-	FP	FP	FP	-	-	-	-
249 Dark Canyon	-	-	FP	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-	-
250 Grand Gulch	MP	MP	FP	-	-	-	FP	FP	-	FP	FP	FP	-	FP	-	FP	FP	-	-	-	-
251 Paiute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
252 Aravaipa Canyon	FP	FP	-	-	-	-	-	-	-	-	-	-	FP	-	FP	FP	-	-	-	-	-

[a] (MP)-a problem in many places; (FP)-a problem in a few places; (-)-not a problem

Table 31.—Carrying capacity, rationing, and permits

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
F.S. WILDERNESS																			
1 Pasayten	2	2	-	50	Y	-	100	-	-	-	-	X	-	-	X	X	X	-	-
2 Glacier Peak	2	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
3 Glacier Peak	3	3	2	10	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
4 Alpine Lakes	4	3	3	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
5 Alpine Lakes	3	2	2	05	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
6 Goat Rocks	3	3	3	10	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
7 Goat Rocks	4	3	2	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
8 Mount Adams	4	3	2	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
9 Wenaha-Tucannon	4	5	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
10 Eagle Cap	4	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
11 Hells Canyon	4	1	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
12 Hells Canyon	4	3	3	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
13 Strawberry Mountain	4	3	2	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
14 Mount Hood	4	2	-	150	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
15 Mount Jefferson	4	2	0	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
16 Mount Jefferson	4	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
17 Mount Jefferson	3	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
18 Mount Washington	3	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
19 Mount Washington	3	1	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
20 Three Sisters	3	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
21 Three Sisters	3	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
22 Diamond Peak	3	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
23 Diamond Peak	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
24 Mountain Lake	4	2	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
25 Gearhart Mountain	4	1	-	80	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
26 Wild Rogue	2	2	-	25	0	0	05	10	20	25	-	-	-	-	X	X	X	-	-
27 Kalmiopsis	4	2	-	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28 Marble Mountain	3	3	2	30	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
29 South Warner	3	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
30 Thousand Lakes	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
31 Caribou	3	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
32 Yolla Bolly-Middle Eel	2	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
33 Desolation	1	3	4	-	Y	-	50	50	-	UK	-	-	X	X	X	X	X	-	-
34 Mokelumne	1	3	3	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
35 Mokelumne	1	2	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
36 Emigrant	1	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
37 Hoover	3	3	2	10	P	-	40	60	-	UK	-	-	X	-	X	X	X	-	D
38 Hoover	4	3	3	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
39 Minarets	3	2	2	10	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
40 Minarets	1	4	4	-	Y	-	35	65	-	UK	-	-	X	-	X	X	X	-	-
41 Kaiser	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
42 John Muir	4	3	2	10	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
43 John Muir	2	4	3	10	Y	-	-	90	-	40	-	-	X	-	X	X	X	-	-
44 Golden Trout	4	1	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
45 Golden Trout	4	2	-	1000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D

See footnotes at end of table 31, p.35

Table 31.—(con.)

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
46 Domeland	4	1	-	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
47 Ventana	3	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
48 Santa Lucia	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
49 San Rafael	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
50 San Gabriel	3	3	2	55	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
51 Cucamonga	1	3	4	-	Y	Y	75	25	-	01	X	-	-	-	X	X	X	-	-
52 San Gorgonio	1	2	-	20	Y	Y	15	85	-	25	X	-	-	-	X	-	X	-	-
53 San Jacinto	1	2	-	-	Y	-	15	85	-	30	X	X	-	-	X	-	X	-	-
54 Aqua Tibia	3	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
55 Jarbidge	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56 Selway-Bitterroot	3	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57 Selway-Bitterroot	2	2	-	50	0	0	-	-	100	10	-	-	-	-	X	-	X	-	-
58 Selway-Bitterroot	3	3	2	30	0	0	-	-	98	10	-	-	-	-	X	-	X	-	0
59 Selway-Bitterroot	3	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
60 Sawtooth	3	2	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0
61 Gospel Hump	4	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
62 Cabinet Mountains	4	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
63 Mission Mountains	3	3	2	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
64 Great Bear	2	1	-	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
65 Bob Marshall	4	3	2	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
66 Bob Marshall	3	3	2	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
67 Scapegoat	4	1	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
68 Scapegoat	4	3	1	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
69 Scapegoat	3	2	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70 Gates of the Mountain	4	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
71 Welcome Creek	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
72 Anaconda-Pintler	3	3	1	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
73 Anaconda-Pintler	1	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
74 Anaconda-Pintler	4	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75 Absaroka-Beartooth	3	3	2	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
76 Absaroka-Beartooth	3	3	1	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
77 North Absaroka	3	2	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
78 Washakie	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0
79 Fitzpatrick	3	2	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0
80 Teton	3	2	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
81 Bridger	4	3	2	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
82 Savage Run	4	1	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
83 Lone Peak	3	2	-	15	P	-	-	-	-	-	-	X	-	-	-	-	-	X	-
84 Lone Peak	3	2	-	15	P	-	-	-	-	-	-	X	-	-	-	-	-	X	-
85 Mount Zirkel	3	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
86 Rawah	3	3	2	15	P	-	75	25	-	-	-	X	-	-	X	-	X	-	C
87 Flat Tops	4	3	2	10	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
88 Flat Tops	3	3	1	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
89 Indian Peaks	4	3	2	—	P	-	-	-	-	-	-	X	-	-	X	-	X	-	-
90 Eagles Nest	4	3	2	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-

See footnotes at end of table 31, p. 35

Table 31.—(con.)

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
91 Marcon Bells-Snowmass	4	3	1	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
92 Hunter Fryingpan	4	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
93 West Elk	3	2	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
94 La Garita	3	2	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
95 Weminuche	3	2	-	100	P	-	-	100	-	-	-	X	-	-	X	X	X	-	-
96 Weminuche	4	2	-	10	P	-	-	-	-	-	-	X	-	-	X	X	X	X	-
97 Sycamore Canyon	3	1	-	400	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
98 Sycamore Canyon	3	3	1	—	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99 Sycamore Canyon	4	2	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100 Pine Mountain	3	3	1	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
101 Mazatzal	4	2	-	—	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
102 Sierra Ancha	4	1	-	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
103 Superstition	3	4	4	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
104 Mount Baldy	1	4	3	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
105 Galiuro	3	1	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
106 Pusch Ridge	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
107 Chiricahua	4	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
108 Wheeler Peak	3	3	2	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
109 San Pedro Parks	3	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
110 Chama River Canyon	4	1	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
111 Pecos	2	3	2	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
112 Pecos	2	3	3	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
113 Manzano Mountains	4	1	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
114 Sandia Mountains	4	3	2	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
115 Gila	4	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
116 White Mountain	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
117 Boundary Waters Canoe Area	1	3	2	30	Y	0	-	100	-	20	-	-	X	-	X	X	X	-	-
118 Rainbow Lake	3	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
119 Whisker Lake	4	1	-	250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
120 Blackjack Springs	4	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
121 Hercules Glades	4	2	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
122 Upper Buffalo	3	1	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
123 Caney Creek	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
124 Bristol Cliffs	4	1	-	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
125 Lye Brook	3	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
126 Great Gulf	1	3	2	100	Y	-	-	100	-	10	-	-	-	X	X	X	X	-	-
127 Presidential-Dry River	3	3	2	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
128 Dolly Sods	4	3	2	—	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
129 Otter Creek	3	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
130 Beaver Creek	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
131 James River Face	4	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
132 Gee Creek	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
133 Joyce Kilmer-Slickrock	4	1	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
134 Joyce Kilmer-Slickrock	4	3	1	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
135 Cohutta	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

See footnotes at end of table 31, p. 35

Table 31.—(con.)

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
136 Cohutta	3	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137 Linville Gorge	1	4	4	33	Y	Y	-	100	-	00	-	-	-	-	X	X	X	-	-
138 Shining Rock	3	1	-	20	-	-	-	-		-	-	-	-	-	-	-	-	X	D
139 Ellicott Rock	3	1	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
140 Ellicott Rock	4	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
141 Sipsey	4	3	2	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
142 Bradwell Bay	3	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F.S. PRIMITIVE AREAS																			
143 Salmon Trinity Alps	3	3	3	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
144 Salmon Trinity Alps	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
145 High Sierra	4	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
146 Salmon River Breaks	3	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
147 Salmon River Breaks	3	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
148 Idaho	4	2	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
149 Idaho	3	3	2	25	0	-	-	-	100	30	X	-	-	-	X	-	-	-	-
150 Idaho	4	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
151 Spanish Peaks	4	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
152 Cloud Peak	3	3	2	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
153 Glacier	3	1	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
154 Popo Agie	4	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0
155 High Unitas	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
156 High Uintas	1	3	2	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
157 Uncompahgre	4	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
158 Wilson Mountains	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
159 Wilson Mountains	3	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
160 Blue Range	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
161 Blue Range	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
162 Gila	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
163 Aldo Leopold-Black Range	4	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
NPS WILDERNESS																			
164 Haleakala	4	2	-	-	Y	-	58	-	42	05	X	-	-	-	X	-	X	-	-
165 Hawaii Volcanoes	3	2	1	200	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
166 Lava Beds	3	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
167 Lassen Volcanic	3	2	-	50	P	-	-	-	-	-	-	-	-	-	-	-	-	X	C
168 Point Reyes	4	1	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
169 Pinnacles	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
170 Joshua Tree	4	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
171 Craters of the Moon	4	1	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
172 Black Canyon of the Gunnison	3	3	4	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
173 Great Sand Dunes	3	1	-	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
174 Mesa Verde	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
175 Petrified Forest	1	1	-	100	Y	Y	100	-	-	-	-	X	-	-	-	-	X	-	-
176 Organ Pipe Cactus	3	2	-	100	Y	-	100	-	-	-	-	X	-	-	X	X	X	-	-
177 Saguaro	1	2	-	-	Y	-	100	-	-	15	X	-	-	-	-	-	X	-	-
178 Chiricahua	1	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-

See footnotes at end of table 31, p. 35

Table 31.—(con.)

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
179 Bandelier	2	2	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
180 Carlsbad Caverns	4	2	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
181 Guadalupe Mountains	4	2	-	UK	Y	-	100	-	-	-	X	-	-	-	-	-	X	-	-
182 Theodore Roosevelt	3	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
183 Badlands	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
184 Isle Royale	3	2	-	20	Y	-	25	75	-	-	-	-	-	X	-	-	X	-	-
185 Buffalo National River	4	2	-	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
186 Shenandoah	3	3	1	15	P	-	-	-	-	-	-	X	-	-	X	X	X	X	C
187 Everglades	3	2	-	20	P	-	25	75	-	-	X	-	-	-	X	-	X	-	-
188 Gulf Islands	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
NPS PROPOSED WILDERNESS																			
189 Mount McKinley	2	2	-	20	Y	-	100	-	-	-	-	X	-	-	X	-	X	-	0
190 Katmai	4	2	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
191 Glacier Bay	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
192 North Cascades Complex	1	3	2	25	Y	-	100	-	-	-	X	X	-	-	-	-	X	-	-
193 Olympic	3	2	-	05	Y	-	75	25	-	05	-	-	X	-	X	X	X	-	-
194 Mount Rainier	1	3	2	50	Y	-	20	80	-	44	X	X	-	-	X	X	X	-	-
195 Crater Lake	3	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
196 Yosemite	1	3	2	62	Y	-	50	50	-	20	-	-	X	-	X	X	X	-	-
197 Sequoia-Kings Canyon	3	3	2	20	Y	-	50	50	-	30	-	-	X	-	X	X	X	-	-
198 Death Valley	4	2	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
199 Glacier	1	2	-	-	Y	-	100	-	-	-	X	X	-	-	-	-	X	-	-
200 Yellowstone	3	3	2	100	Y	-	100	-	-	-	X	-	-	-	-	-	X	-	-
201 Grand Teton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202 Dinosaur	2	3	4	-	0	0	10	-	90	60	-	X	-	-	X	-	-	-	-
203 Rocky Mountain	1	2	-	-	Y	-	78	22	-	10	X	X	-	-	X	X	X	-	-
204 Colorado	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
205 Zion	3	2	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
206 Cedar Breaks	4	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207 Bryce Canyon	3	2	-	100	Y	-	100	-	-	-	X	-	-	-	-	-	X	-	-
208 Capitol Reef	4	1	-	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
209 Canyonlands	3	1	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
210 Arches	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
211 Cumberland Gap	1	2	-	UK	Y	-	15	84	-	15	X	-	-	-	X	X	X	-	-
212 Great Smoky Mountains	1	2	-	20	Y	-	28	72	-	02	X	-	-	-	X	X	X	-	-
F&WS WILDERNESS																			
213 San Juan Islands	4	2	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
214 Red Rocks Lakes	3	1	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
215 Crab Orchard	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
216 Mingo	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
217 Wichita Mountains	3	2	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
218 Lacassine	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
219 Breton	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
220 Monomy	3	2	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C

See footnotes at end of table 31, p.35

Table 31.—(con.)

	Carrying Capacity						Rationing technique				Ration permits issued for:				Ration permits obtained by:				
	Assessment progress[a]	Relation to use[b]	Overuse solution[c]	Could increase use by (%)[d]	Use rationing[e]	Day-use rationing[f]	First-come, first-serve	Reservations	Lottery	Percent "no-shows"	Campsites	Travel Zones	Trailheads	Entire area	Mail	Telephone	In person	Future need to ration	Mandatory permit required[g]
221 Great Swamp	2	3	2	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
222 Cape Romain	3	2	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
223 Blackbeard Island	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
224 Wolf Island	3	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
225 Okefenokee	3	1	-	80	P	-	-	100	-	20	X	X	X	-	X	X	X	X	C
226 Cedar Keys	3	1	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
227 Chassahowitzka	1	1	-	400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
228 Passage Key	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
229 J.N. "Ding" Darling	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F&WS PROPOSED WILDERNESS																			
230 Aleutian Islands	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
231 Nunivak	4	1	-	UK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
232 Kenai	4	2	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
233 Kenai Lakes	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
234 Hart Mountain	3	1	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	X	C
235 Havasu	4	3	1	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
236 Charles M. Russell	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
237 Desert	1	2	-	100	Y	-	100	-	-	-	-	-	X	-	-	-	X	-	-
238 Kofa	4	1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
239 Cabeza Prieta	4	1	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
240 Missiquoi	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0
241 Parker River	4	4	4	-	Y	Y	95	05	-	01	-	-	-	X	X	X	X	-	-
BLM PRIMITIVE AREAS																			
242 Chemise Mountains	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
243 Humbug Spires	4	1	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
244 Beartrap Canyon	4	1	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
245 Centennial Mountains	4	1	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
246 Scab Creek	4	1	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
247 Powderhorn	3	3	2	50	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
248 Paria Canyon	4	2	-	100	P	-	-	-	-	-	-	-	-	-	-	X	X	-	C
249 Dark Canyon	4	2	-	55	-	-	-	-	-	-	-	-	-	-	-	-	-	X	D
250 Grand Gulch	4	1	-	100	P	-	-	-	-	-	-	-	X	-	X	X	X	X	D
251 Paiute	4	1	-	5000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
252 Aravaipa Canyon	4	2	-	20	Y	Y	-	X	-	50	-	-	-	X	X	X	X	-	-

[a] (1)-limits established throughout area; (2)-limits established for some parts; (3)-limits estimated for some parts; (4)-unable to estimate limits.
[b] (1)-capacity never exceeded; (2)-sometimes exceeded in places; (3)-usually exceeded in places; (4)-usually exceeded throughout area
[c] Overuse controlled by: (1)-local dispersal or control; (2)-dispersal to other parts of the area but some parts still under-used; (3)-dispersal to other parts of the area with all parts at capacity; (4)-redistribution not sufficient, total use must be reduced.
[d] Amount by which use could be increased (%); (-)use cannot be increased.
[e] (Y)-use is rationed; (P)-rationing planned in 1-2 years; (-)no plans to ration; (0)-one type of use is rationed.
[f] (0)-one type of day use is rationed; (Y)-day use is rationed.
[g] (C)-permit required for overnight use only; (D)-permit required for day and overnight use; (0)-permit required for one type of use only

Table 32.—Party-size, length-of-stay, access, and site hardening

F.S. WILDERNESS	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control				Designated trailless zones	Site-Hardening and Facilities												
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance		Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
1 Pasayten	12	18	-	-	X	-	-	X	-	X	-	-	X	-	-	-	-	X	-	X	-	-
2 Glacier Peak	12	15	-	-	X	X	-	-	X	X	-	-	-	-	-	-	-	X	-	-	-	-
3 Glacier Peak	12	15	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
4 Alpine Lakes	C	C	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
5 Alpine Lakes	12	12	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-
6 Goat Rocks	12	15	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
7 Goat Rocks	12	6	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
8 Mount Adams	12	-	-	-	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Wenaha-Tucannon	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-
10 Eagle Cap	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
11 Hells Canyon	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
12 Hells Canyon	-	-	14	-	-	-	-	-	-	-	X	-	X	-	-	-	X	X	-	-	-	-
13 Strawberry Mountain	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14 Mount Hood	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-
15 Mount Jefferson	C	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16 Mount Jefferson	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
17 Mount Jefferson	C	C	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
18 Mount Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19 Mount Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20 Three Sisters	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
21 Three Sisters	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-
22 Diamond Peak	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23 Diamond Peak	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24 Mountain Lake	C	C	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
25 Gearhart Mountain	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
26 Wild Rogue	0	-	14	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-
27 Kalmiopsis	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
28 Marble Mountain	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
29 South Warner	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30 Thousand Lakes	V	V	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31 Caribou	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32 Yolla Bolly-Middle Eel	V	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33 Desolation	25	-	-	14	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	X
34 Mokelumne	25	-	-	14	-	-	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-
35 Mokelumne	25	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
36 Emigrant	15	20	-	21	-	-	X	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-
37 Hoover	15	20	14	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
38 Hoover	25	-	-	14	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
39 Minarets	25	-	-	V	-	-	-	-	X	-	-	-	X	-	-	-	-	X	-	-	-	-
40 Minarets	25	-	-	V	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
41 Kaiser	25	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42 John Muir	25	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
43 John Muir	25	-	-	V	-	-	-	-	X	-	-	-	-	-	X	-	-	X	-	-	-	-
44 Golden Trout	25	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	X	-	-	-	-
45 Golden Trout	25	-	-	-	-	-	-	-	-	X	X	-	X	X	-	-	X	-	-	-	-	-
46 Domeland	25	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47 Ventana	25	-	-	-	-	-	-	-	-	X	X	-	X	-	-	-	-	-	-	-	-	-
48 Santa Lucia	25	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-
49 San Rafael	C	C	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	X	-	-	-	-
50 San Gabriel	25	-	14	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
51 Cucamonga	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52 San Gorgonio	15	-	02	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-
53 San Jacinto	15	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
54 Aqua Tibia	15	08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55 Jarbidge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

See footnotes at end of table 32, p. 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control				Designated trailless zones	Site-Hardening and Facilities												
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance		Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
56 Selway-Bitterroot	20	20	-	14	-							-	-		-	-	-	-	-	-	-	-
57 Selway-Bitterroot	20	20	14	-	-		X		X	X	X	-	X				X	-	-			-
58 Selway-Bitterroot	20	20	14		-	-	-	-	X		-	-					X	X	-	-		
59 Selway-Bitterroot	20	20	-	14	X	-						-			-						-	-
60 Sawtooth	20	30	-		X			X	X	-	-	-	-		X		X	X	-	-	-	-
61 Gospel Hump		-	14			-			X					-	-	-	X	-	-	-	-	-
62 Cabinet Mountains	-				X	-	X	X	X	X		-	-	X		-	-	-	-	-		-
63 Mission Mountains	-	-	-		-			X	X		-				-						-	-
64 Great Bear	V	V	14	-					-						-		-	-	-	-		
65 Bob Marshall	15	35	15			-	-					-	-	-			X			X		-
66 Bob Marshall	15	35	-	14	-				X	-					-		-	-	-	-	-	-
67 Scapegoat	-	-	15			-				-	-	-					X				-	-
68 Scapegoat	-	-	-	15		-				-	-				-	-	-	-	-	-		
69 Scapegoat	15	35	14			-							-	-		-	-	-	-	-	-	-
70 Gates of the Mountain	-	-	14	-	-						-	-	-	X								
71 Welcome Creek	-		-	14	X	X			X	X				-	-	-	-	-		-	-	-
72 Anaconda-Pintler	15	20	14			-			X			-					-			-	-	
73 Anaconda-Pintler	15	20	14		-			-		-		-				-	-	-	-	-		-
74 Anaconda-Pintler	15	20	14	-	X		-	X	X		-			-		-				-	-	
75 Absaroka-Beartooth	-	25-35	-	-	X	-	X	X	X			-	-				-	-	-	-		-
76 Absaroka-Beartooth	-	-	-			-	-		X	-	-				-	-	-					
77 North Absaroka		-			-		-		-	-				-	-		-	-			-	-
78 Washakie	20	35	10	-	-	-		X	-		-	-					-	-	-	-		
79 Fitzpatrick	20	30	-	-		-		X	X	-	-			-	-	-			-			-
80 Teton	20	50		14	-	-	-		-	-	-						X	X	-	-	-	-
81 Bridger	V	V	-	-	-	-	-	X	X		-	-	-		-	-	-			-	-	
82 Savage Run	0	-				-					-			-	-	-	-		-		-	
83 Lone Peak	-	-	-	01		-			X	-	-	-	-		X		-	-	-	-		
84 Lone Peak	-	-		-	-		-	X	X			-			-		X					-
85 Mount Zirkel	-	-			-			X	X	-	-			-	-			-	-	-	-	-
86 Rawah	-	-	14		-			-	-	-		-	-		-	-	-			-	-	X
87 Flat Tops	15	15	10		-						-		-	-			-	-	-	-		
88 Flat Tops	15	15	-	10		-		X		-			-				-	-	-			-
89 Indian Peaks	-	-		14	-	-		X		-		-			-	-	X			-		
90 Eagles Nest	10	10	14	-	x	X		X	-	-	-		-	-			-	-	-			
91 Maroon Bells-Snowmass	10	10	-		X	-		-	X	X		-	-		-			-	-	-	-	-
92 Hunter Fryingpan	10	10		-		-	-		-		-	-	-	-			-	-		-	-	
93 West Elk	-	-	-	-	-		-	-			-		-			-	-	-				-
94 La Garita	-	-	-		-	-			-	-		-						-	-	-	-	
95 Weminuche	15	20	30	30		-	-	X	X		-	-	-	-		-	-					
96 Weminuche	-	-	-		-	-			X	-	-	-		-	-			-	-			
97 Sycamore Canyon	-	-	-	14	-		-	-		-		-						-			-	
98 Sycamore Canyon	-	-	-	14	-	-	-	-	-	-	-			-			-					
99 Sycamore Canyon	-		-	14		-	-		-		-		-		-	-		-	-	-	-	
100 Pine Mountain	25	-	14	-	-		-	-		-		-		-		-						
101 Mazatzal	0	25	-	14	X	X	X	X	X	-	-				-			-		-		
102 Sierra Ancha	0	25	14	14	X	X	X	X	X	-	-		-			-						
103 Superstition	25	25	14	14	X	X	X	X	-		-	-	-	-				-	-		-	-
104 Mount Baldy	6-12	6-12	-	14		-				-							-					
105 Galiuro	-	-	14	-	X	-					-				-			-	-			-
106 Pusch Ridge	14		-	14	-		-	X	-	-	-				-			-	-	-	-	
107 Chiricahua	-	-		-		-	-		-	-		-		-			X			-	-	
108 Wheeler Peak	20	20	-	-	-	-	-			-	-								-	-	-	
109 San Pedro Parks	15	15	-	14	-	-		-	-			-		-			-					
110 Chama River Canyon	12	06	14	-		-	-		-	-	-	-	-					-		-	-	-

See footnotes at end of table 32, p 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control					Site-Hardening and Facilities												
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance	Designated trailless zones	Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
111 Pecos	15	10	07	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
112 Pecos	15	15	-	30	-	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
113 Manzano Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
114 Sandia Mountains	-	-	14	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	X	X
115 Gila	25	-	-	30	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
116 White Mountain	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
117 Boundary Waters Canoe Area	10	-	24	-	X	-	-	-	-	-	X	-	-	-	-	-	X	X	-	-	-	X
118 Rainbow Lake	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119 Whisker Lake	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
120 Blackjack Springs	-	-	14	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
121 Hercules Glades	10	06	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
122 Upper Buffalo	-	-	14	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
123 Caney Creek	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
124 Bristol Cliffs	10	-	-	14-21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
125 Lye Brook	10	-	-	14-21	-	-	-	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-
126 Great Gulf	10	-	-	4-14	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X
127 Presidential-Dry River	-	-	-	-	-	-	-	-	-	X	X	-	-	X	-	-	X	X	-	-	-	X
128 Dolly Sods	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
129 Otter Creek	10	-	-	14	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-
130 Beaver Creek	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
131 James River Face	-	-	-	-	X	-	-	X	-	X	X	-	X	-	-	-	X	-	-	-	-	-
132 Gee Creek	-	-	14	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
133 Joyce Kilmer-Slickrock	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
134 Joyce Kilmer-Slickrock	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
135 Cohutta	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
136 Cohutta	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137 Linville Gorge	10	-	-	03	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
138 Shining Rock	10	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
139 Ellicott Rock	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
140 Ellicott Rock	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
141 Sipsey	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
142 Bradwell Bay	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
F.S. PRIMITIVE AREAS																						
143 Salmon Trinity Alps	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
144 Salmon Trinity Alps	25	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
145 High Sierra	25	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
146 Salmon River Breaks	20	20	14	-	-	-	-	X	X	-	-	-	-	-	-	-	-	X	-	-	-	-
147 Salmon River Breaks	15	10	14	-	-	-	-	-	-	-	-	-	-	X	-	-	X	X	-	-	-	-
148 Idaho	-	-	-	-	-	-	-	X	X	-	X	-	X	-	-	-	X	-	-	-	-	-
149 Idaho	V	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
150 Idaho	30	20	14	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
151 Spanish Peaks	10	15	15	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
152 Cloud Peak	20	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
153 Glacier	20	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
154 Popo Agie	20	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
155 High Uintas	20	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-
156 High Uintas	15	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
157 Uncompahgre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-
158 Wilson Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
159 Wilson Mountains	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
160 Blue Range	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
161 Blue Range	-	-	-	30	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
162 Gila	25	-	-	30	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
163 Aldo Leopold-Black Range	20	30	-	30	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-

See footnotes at end of table 32, p. 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control				Designated trailless zones	Site-Hardening and Facilities											
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance		Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
NPS WILDERNESS																						
164 Haleakala	15	-	02	03	-	-	-	-	X	X		-	-	X	-		X	-		-	-	-
165 Hawaii Volcanoes	-	-	-	-	X	-				X	X	-	X	X			X	-	-	-	-	-
166 Lava Beds	-	-	14	-	-	-	-	-	-			-	-	-	-	-		-	-	-	-	-
167 Lassen Volcanic	10	15	-	07	-			-			-	-	-	-	-	-	-	-	-	-	-	-
168 Point Reyes	25	-	01	03		-	-	-		-	X	-	X	X	X			-	-	-	-	
169 Pinnacles	-		-	01	-	-			-	-		-	-	-	-		-	X	-	-	-	
170 Joshua Tree	-	-	0	30	X	-		-	X		-	-	-	-	-			-	-	-	-	-
171 Craters of the Moon	-	-	-	-	-	-		-			-	-		-	-		-	-	-	-		-
172 Black Canyon of the Gunnison	-	-	-		-	-	-	-		-	-		-	-	X	-	-	-	-	-	-	-
173 Great Sand Dunes	-	-	14	-			-		X	-		-	-	-		-	-	-	-	-		
174 Mesa Verde	-	-	-			-		-	-		-	-		-	-		-	-	-	-		-
175 Petrified Forest	15	06	-	-	X	X	X	-	X		-	-		-	-	-	-	-		-	-	-
176 Organ Pipe Cactus	10	10	-	07	X	-	X			-			-		-	-	-	-	-	-	-	X
177 Saguaro	15	5	-	10	-			-	-	-	X	-	X	-	-	-	X	-	-	-	-	-
178 Chiricahua	-			01		-		-	X	-	-	-	-	-	-	-	X	-	-	-	-	-
179 Bandelier	10	12	02	14	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-
180 Carlsbad Caverns	-	-	14	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
181 Guadalupe Mountains	-	14	-	-	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
182 Theodore Roosevelt	-	06	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
183 Badlands	-	20	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
184 Isle Royale	15	-	1-7	15	-	-	-	-	X	X	X	-	X	-	-	-	X	X	-	-	-	-
185 Buffalo National River	-	-	-	-	X		-		X		-	-	-		-	-		-	-		-	-
186 Shenandoah	10	-	02	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
187 Everglades	-		-	14	-	-	-	-	-	X	-	-	X	-	X	-	-	-	-	-	-	-
188 Gulf Islands	-	-		30	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
NPS PROPOSED WILDERNESS																						
189 Mount McKinley	V	-		-	-	-		-	X		-	-	-		-		-	-		-	-	-
190 Katmai	12	15	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X	-	-		-
191 Glacier Bay	-	-	-	-	-		-	X	-			-		-	-	-		-	-	-	-	
192 North Cascades Complex	12	-	-	-		-		-	X	X	X		-		-	-	-	X		-	-	-
193 Olympic	12	08	-	-	X	-	-	-	X	X	-	-	-	-	X	-	X	X	-			
194 Mount Rainier	06	05	14	-	-	-	-	-	X	X	X	-	-	-	-	-	X	X	-	-	-	-
195 Crater Lake	-	-	-	-	-	-		-		-	-	-	-		-	-	-	-		-	-	-
196 Yosemite	25	25	-	14	-	-	-	-	X	-	-	-	-	-	-	-	-	-		-		
197 Sequoia-Kings Canyon	25	20	1-2	-	-	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-
198 Death Valley	-	-		-	-		-	-			-	-	-	X	-	-	-	-	-	-	-	-
199 Glacier	12	10	1-3	6	-	-	-	X	-	X	X	-	-	-	-	-	X	X	-	-	-	X
200 Yellowstone	V	V	-	14-30	X	-	-	X	X	-	-	-	X	-	-	-	X	X	-	-	-	-
201 Grand Teton	-	-	-	-		-	-	-		-	-		-	-	-	-	-	-	-		-	
202 Dinosaur	-		2			-	-	-		-	-	-	-	-		-	X	X	-		-	
203 Rocky Mountain	1-20	20	3	7-15	-	-		-	-		X	-		-	X	-	X	X	-	-	-	-
204 Colorado	-	-	14	-	X	-			-	-		-	-		-	-	-	-	-	-	-	-
205 Zion	12	8	-	14	-	X	-	-	X	-	-	-	-	-	-	-	X	-	-	X	-	-
206 Cedar Breaks	-	-	-	-	-			-	-	-		-			-		-		-		-	
207 Bryce Canyon	5	-	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
208 Capitol Reef	-	-	14		-	-	-	-	X	-	-	-	-	-	-	-		-		-	-	
209 Canyonlands	V	V	-	-			-	-	X	-	-		-		-			-	-			X
210 Arches	-	-	-		X	X	-	-	X	-	-	-	-	-	-	-	-	-	-	X	X	-
211 Cumberland Gap	V	10	-	14	-	-	-	-	-	X	X	X	X	-	-		X	-	X		-	-
212 Great Smoky Mountains	8	-	1-3	14	X	-	-	-	-	X	-	-		-	-			X	-	-	-	
F&WS WILDERNESS																						
213 San Juan Islands	-	-		-	-			-	-	-	-	-	-	-	-	-		-	-		-	-
214 Red Rocks Lakes	-	-	-	-	-	-	-		X	-	-	-	-	-		-		-	-	-		
215 Crab Orchard	-		-	1	X		-	-	X			-	-	-	-		-	-	-	-	-	-

See footnotes at end of table 32, p. 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control					Site-Hardening and Facilities												
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance	Designated trailless zones	Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
111 Pecos	15	10	07	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
112 Pecos	15	15	-	30	-	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
113 Manzano Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
114 Sandia Mountains	-	-	14	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	X	X
115 Gila	25	-	-	30	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
116 White Mountain	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
117 Boundary Waters Canoe Area	10	-	24	-	X	-	-	-	-	-	X	-	-	-	-	-	X	X	-	-	-	X
118 Rainbow Lake	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119 Whisker Lake	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
120 Blackjack Springs	-	-	14	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
121 Hercules Glades	10	06	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
122 Upper Buffalo	-	-	14	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
123 Caney Creek	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
124 Bristol Cliffs	10	-	-	14-21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
125 Lye Brook	10	-	-	14-21	-	-	-	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-
126 Great Gulf	10	-	-	4-14	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X
127 Presidential-Dry River	-	-	-	-	-	-	-	-	-	X	X	-	-	X	-	-	X	X	-	-	-	X
128 Dolly Sods	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
129 Otter Creek	10	-	-	14	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-
130 Beaver Creek	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
131 James River Face	-	-	-	-	X	-	-	X	-	X	X	-	X	-	-	-	X	-	-	-	-	-
132 Gee Creek	-	-	14	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
133 Joyce Kilmer-Slickrock	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
134 Joyce Kilmer-Slickrock	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
135 Cohutta	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
136 Cohutta	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137 Linville Gorge	10	-	-	03	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
138 Shining Rock	10	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
139 Ellicott Rock	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
140 Ellicott Rock	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
141 Sipsey	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
142 Bradwell Bay	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
F.S. PRIMITIVE AREAS																						
143 Salmon Trinity Alps	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
144 Salmon Trinity Alps	25	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
145 High Sierra	25	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
146 Salmon River Breaks	20	20	14	-	-	-	-	X	X	-	-	-	-	-	-	-	-	X	-	-	-	-
147 Salmon River Breaks	15	10	14	-	-	-	-	-	-	-	-	-	-	X	-	-	X	X	-	-	-	-
148 Idaho	-	-	-	-	-	-	-	X	X	-	X	-	X	-	-	-	X	-	-	-	-	-
149 Idaho	V	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
150 Idaho	30	20	14	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
151 Spanish Peaks	10	15	15	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
152 Cloud Peak	20	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
153 Glacier	20	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
154 Popo Agie	20	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
155 High Unitas	20	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-
156 High Uintas	15	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
157 Uncompahgre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-
158 Wilson Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
159 Wilson Mountains	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
160 Blue Range	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
161 Blue Range	-	-	-	30	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
162 Gila	25	-	-	30	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
163 Aldo Leopold-Black Range	20	30	-	30	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-

See footnotes at end of table 32, p. 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control				Designated trailless zones	Site-Hardening and Facilities												
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance		Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
NPS WILDERNESS																						
164 Haleakala	15		02	03	-	-	-		X	X	-	-	-	X	-	-	X			-		
165 Hawaii Volcanoes	-	-	-		X	-	-	-	-	X	X	-	X	X	-		X	-	-	-	-	-
166 Lava Beds	-	-	14	-	-	-		-	-	-		-	-		-	-	-	-	-	-	-	-
167 Lassen Volcanic	10	15	-	07	-	-	-	-	-		-	-	-	-	-	-		-		-	-	-
168 Point Reyes	25	-	01	03	-			-	-	-	X	-	X	X	X	-	-	-	-		-	-
169 Pinnacles	-	-	-	01	-	-	-			-			-	-	-	-	-	X	-	-	-	-
170 Joshua Tree	-		0	30	X	-			X	-	-	-	-		-	-	-	-	-	-	-	-
171 Craters of the Moon	-	-	-		-	-		-	-		-	-	-	-	-	-		-	-	-	-	-
172 Black Canyon of the Gunnison	-	-	-		-	-	-	-	-		-	-	-	-	X	-	-	-	-	-		-
173 Great Sand Dunes	-	-	14	-	-		-	-	X	-	-	-	-	-	-			-	-	-	-	-
174 Mesa Verde	-	-		-	-	-	-			-		-	-		-	-	-		-	-	-	-
175 Petrified Forest	15	06	-	-	X	X	X		X			-		-	-			-	-	-	-	-
176 Organ Pipe Cactus	10	10	-	07	X	-	X	-	-	-	-	-		-	-		-	-	-	-	-	X
177 Saguaro	15	5	-	10	-	-		-			X	-	X	-			X	-	-	-	-	-
178 Chiricahua	-	-		01		-	-		X			-	-	-	-		X		-	-	-	-
179 Bandelier	10	12	02	14		-		X	-	X	-	-	-	-			-	-	-	-	-	-
180 Carlsbad Caverns	-		14	14	-	-	-	-	-	-		-	-		-	-		-	-	-	-	
181 Guadalupe Mountains	-	14	-		X		X		X	-	-	-	-	-	-	-	-	-	-	-	-	-
182 Theodore Roosevelt	-	06	-	14	-	-	-		-			-		-	-	-	-	-	-	-	-	-
183 Badlands	-	20	-		-		-		X	-	-	-		-	-	-	-	-	-			
184 Isle Royale	15	-	1-7	15		-		-	X	X	X		X		-	-	X	X	-	-	-	-
185 Buffalo National River		-	-	-	X	-	-	-	X	-	-	-		-	-		-	-		-	-	-
186 Shenandoah	10	-	02	-	-	-	X	X	-	-		-		-		-	-	-	-	-	-	
187 Everglades	-		-	14	-		-		-	X	-	-	X	-	X	-		-	-	-	-	-
188 Gulf Islands		-		30		-		-		-		-		X	-		-	-	-		-	
NPS PROPOSED WILDERNESS																						
189 Mount McKinley	V	-	-	-		-	-	-	X	-		-	-	-	-	-	-			-	-	-
190 Katmai	12	15	-	-	-	-		-		X		-		-		-		X	-	-		-
191 Glacier Bay	-	-	-	-	-	-		X	-	-	-	-			-	-		-	-	-	-	-
192 North Cascades Complex	12	-	-	-	-	-	-	-	X	X	X	-		-		-		X		-	-	-
193 Olympic	12	08	-		X	-		-	X	X		-	-	-	X	-	X	X	-	-		
194 Mount Rainier	06	05	14	-	-	-	-		X	X	X	-	-	-	-		X	X	-	-	-	-
195 Crater Lake	-	-	-	-	-		-	-	-		-	-		-	-	-	-	-		-	-	-
196 Yosemite	25	25	-	14	-	-		-	X	-	-	-	-	-	-			-	-	-	-	
197 Sequoia-Kings Canyon	25	20	1-2	-	-	-	-	-	-		-	-	-	-	X	-	-	X		-	-	-
198 Death Valley	-		-	-		-	-		-	-		-	-	X			-		-	-	-	-
199 Glacier	12	10	1-3	6	-	-	-	X	-	X	X	-		-	-	-	X	X	-	-	-	X
200 Yellowstone	V	V	-	14-30	X		-	X	X	-	-		X		-		X	X		-	-	-
201 Grand Teton	-	-	-		-	-			-	-		-		-	-	-	-	-	-	-	-	-
202 Dinosaur	-	-	2	-		-	-		-	-		-	-	-	-	-	X	X	-	-	-	-
203 Rocky Mountain	1-20	20	3	7-15	-	-	-	-	-	-	X		-	-	X		X	X		-	-	-
204 Colorado	-	-	14	-	X	-		-	-		-	-	-	-	-	-	-	-		-	-	-
205 Zion	12	8	-	14	-	X	-		X	-		-	-		-	-	X	-		X	-	-
206 Cedar Breaks	-		-	-		-		-	-	-	-			-	-	-	-		-	-	-	-
207 Bryce Canyon	5	-	3	5	-	-	-	-	-		-	-		-	-	-	-	-	-	-	-	-
208 Capitol Reef	-	-	14	-		-	-		X	-	-		-		-	-	-	-			-	
209 Canyonlands	V	V	-	-		-	-	-	X	-	-	-	-	-			-	-	-			X
210 Arches	-		-	-	X	X		-	X	-	-	-		-	-	-		-	-	X	X	-
211 Cumberland Gap	V	10	-	14	-	-		-		X	X	X	X	-			X		X	-		
212 Great Smoky Mountains	8	-	1-3	14	X	-		-		X	-		-		-			X		-	-	-
F&WS WILDERNESS																						
213 San Juan Islands	-	-	-		-	-	-	-	-	-		-		-		-		-	-	-		
214 Red Rocks Lakes	-	-	-	-	-	-	-		X	-	-	-	-		-			-	-	-	-	-
215 Crab Orchard	-	-		1	X	-	-	-	X		-		-	-	-	-	-			-	-	-

See footnotes at end of table 32, p. 40

Table 32.—(con.)

	Party-size limit[a]		Length of-stay limits (days)[b]		Access Control				Designated trailless zones	Site-Hardening and Facilities											
	People	Stock	At campsites	In entire area	Close roads	Reduce road maintenance	Close trails	Reduce trail maintenance		Shelters	Constructed fireplaces	Non-native turf grasses	Tables	Potable water provided	Vault toilets	Composting toilets	Enclosed outhouses	Open-pit toilets	Trash cans	Trail soil cement	Trail paving	Trail stairways
216 Mingo	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
217 Wichita Mountains	-	-	-	1	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X
218 Lacassine	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
219 Breton	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
220 Monomy	V	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
221 Great Swamp	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
222 Cape Romain	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
223 Blackbeard Island	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
224 Wolf Island	-	-	-	1	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
225 Okefenokee	0	-	1	5	-	-	-	-	X	X	-	-	-	-	X	-	-	-	-	-	-	-
226 Cedar Keys	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
227 Chassahowitzka	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
228 Passage Key	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
229 J.N. "Ding" Darling	-	-	-	1	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
F&WS PROPOSED WILDERNESS																						
230 Aleutian Islands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
231 Nunivak	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
232 Kenai	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
233 Kenai Lakes	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
234 Hart Mountain	-	-	-	14	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
235 Havasu	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
236 Charles M. Russell	-	-	14	14	X	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
237 Desert	8	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
238 Kofa	-	-	-	14	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
239 Cabeza Prieta	-	-	-	-	X	X	-	-	X	-	X	-	X	X	-	-	-	-	-	-	-	-
240 Missiquoi	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
241 Parker River	60	-	-	1	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
BLM PRIMITIVE AREAS																						
242 Chemise Mountain	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
243 Humbug Spires	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
244 Beartrap Canyon		-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
245 Centennial Mountains	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
246 Scab Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
247 Powderhorn	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
248 Paria Canyon	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
249 Dark Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
250 Grand Gulch	25	15	-	-	X	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
251 Paiute	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-
252 Aravaipa Canyon	10	5	-	3	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	-

[a] (V)-party size limit varies by travel zone; (C)-limit composed of a combination of hikers and horses; (0)-limits on one type of use only.
[b] (V)-length of stay limit varies by travel zone.

Table 33.—Packstock and campsite management

F.S. WILDERNESS	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[d]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
1 Pasayten	-	-	A	A	-	-	-	A	-	X	X	-	-	-		-	20		X	X	-	-	-	3
2 Glacier Peak	-	A	A	-	-	-	-	-	A	-	-	-		-	X	-	00		X	-	X	-	-	2
3 Glacier Peak	-	A	A	-	-	-	-	A	-	-	X	-	-	X	X	-	00	-	X	X		-	-	3
4 Alpine Lakes	-	A	A	-	-	-	-	-	-	-	X	-	-	-	-	-	00	-	-	-	-	-	-	2
5 Alpine Lakes	-	A	A	A	-	-	-	-	-	-	X	-	-	X	-	-	00	-	X		X	-	-	2,3
6 Goat Rocks	-	-	A	-	-	-	-	-	-	-	X	X		-	X	-	00	-	X	X		-	-	2,3
7 Goat Rocks	-	A	A	-	-	-	-	-	-	-	X	X	-	-	X	-	100	UK	X	-	-	-	-	3
8 Mount Adams	-	-	A	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	X	-	-	-	3
9 Wenaha-Tucannon	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
10 Eagle Cap	-	A	A	-	-	-	-	-	-	-	X	-	-	-	X	-	00	-	-	-	-	-	-	1
11 Hells Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]
12 Hells Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2,3
13 Strawberry Mountain	-	-	A	-	-	-	-	A	-	-	X	-	-		X	-	00	-	-	-	-	-	-	3
14 Mount Hood	-	A	-	-	-	-	-		A	X	X	-	-	-	-	-	-	-	-	-	-	-	-	3
15 Mount Jefferson	-	-	A	-	-	-	-	-	-	-	X	X	X	-	-	-		-	-	X	-	-	-	3
16 Mount Jefferson	-	-	A	-	-	-	-	-	-	-	X	-	-	-	-	-	-		-	X	-	-	-	3
17 Mount Jefferson	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	3
18 Mount Washington	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
19 Mount Washington	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
20 Three Sisters	-	-	A	-	-	-	-	-		-	-	-	-	-	-	-	100	-	X	-	-	-	-	3
21 Three Sisters	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	3
22 Diamond Peak	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
23 Diamond Peak	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	3
24 Mountain Lake	-	-	A	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	3
25 Gearhart Mountain	-	-	A	-	-	-	-	-	-	-	X	-	-	-	-	-	00	-	-	-	-	-	-	3
26 Wild Rogue	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
27 Kalmiopsis	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
28 Marble Mountain	-	A	A	-	-	A	-	A	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	3
29 South Warner	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
30 Thousand Lakes	-	-	A	-	-	-	-	A	-	-	X	-	-	-	-	-	01	-	-	-	-	-	-	3
31 Caribou	-	-	-	-	-	-	A	A	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	3
32 Yolla Bolly-Middle Eel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
33 Desolation	-	-	A	-	-	-	-	A	A	-	X	-	-	-	-	-	-	-	-	X	-	-	-	3
34 Mokelumne	-	A	A	-	-	-	-	A	A	-	X	-	-	-	-	-	-	-	-	-	-	-	-	2
35 Mokelumne	-	-	A	-	-	-	-	A	-	-	X	X	-	-	-	-	-	-	-	X	-	-	-	1
36 Emigrant	-	-	A	-	-	-	-	-	A	-	X	-	-	-	-	-	-	-	-	-	-	-	-	3
37 Hoover	-	-	-	-	-	A	A	A	A	-	X	-	-	-	X	S	00	-	-	-	X	X	-	3
38 Hoover	-	-	A	-	-	A	-	A	A	-	X	-	-	-	-	-	-	-	-	-	-	-	-	3
39 Minarets	-	-	A	-	-	A	-	-	A	X	X	X	-	-	-	-	-	-		X	-	-	-	3
40 Minarets	-	-	A	-	-	A	-	A	A	-	X	X	-	-	X	-	UK	-	X	-	X	-	-	2
41 Kaiser	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
42 John Muir	-	-	A	-	-	-	A	-	A	-	X	-	-	X	X	-	00	-	-	-	-	-	-	3
43 John Muir	-	A	A	-	-	A	-	-	-	-	X	X	-	-	X	-	00	T	X	X	-	-	-	2
44 Golden Trout	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
45 Golden Trout	-	-	-	-	-	-	-	A	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	3
46 Domeland	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	4
47 Ventana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	00	-	-	-	-	X	-	-
48 Santa Lucia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	T	-	-	-	X	-	-
49 San Rafael	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	50	B	-	-	-	X	-	3
50 San Gabriel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	1

See footnotes at end of table 33, p. 46

Table 33.—(con.)

	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[d]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
51 Cucamonga	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	X	-	-
52 San Gorgonio	-	-	-	-	-	-	-	-	-	-	X	X	X	-	X	S	00	-	-	-	-	X	-	3
53 San Jacinto	-	-	-	-	-	-	-	-	A	-	X	X	X	-	-	A	00	-	-	-	-	X	-	2
54 Aqua Tibia	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	100	T	-	-	-	-	X	-
55 Jarbidge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
56 Selway-Bitterroot	-	A	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
57 Selway-Bitterroot	-	-	-	-	-	-	-	-	A	-	-	-	-	X	X	-	100	-	-	-	-	-	-	1
58 Selway-Bitterroot	-	-	-	-	-	A	C	C	A	-	-	-	-	X	-	-	100	-	-	-	-	-	-	1
59 Selway-Bitterroot	-	-	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
60 Sawtooth	-	-	A	-	-	-	-	-	-	-	-	X	-	X	-	-	00	-	X	-	-	-	-	2
61 Gospel Hump	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2,3
62 Cabinet Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
63 Mission Mountains	-	A	-	-	-	-	-	-	-	-	X	-	-	-	X	-	00	-	X	X	-	-	-	1
64 Great Bear	-	-	C	-	C	-	C	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
65 Bob Marshall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
66 Bob Marshall	-	-	A	-	-	-	-	-	-	X	X	-	-	-	X	-	100	-	-	-	-	-	-	1
67 Scapegoat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
68 Scapegoat	-	-	A	-	-	-	C	C	A	-	X	-	-	-	-	A	-	-	-	-	-	-	-	1
69 Scapegoat	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
70 Gates of the Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
71 Welcome Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
72 Anaconda-Pintler	-	A	-	-	-	-	-	-	A	-	-	-	-	-	X	-	00	-	-	-	-	-	-	1
73 Anaconda-Pintler	-	A	-	-	-	-	-	-	-	-	-	-	X	X	-	-	UK	-	-	-	-	-	-	-
74 Anaconda-Pintler	-	A	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
75 Absaroka-Beartooth	-	-	C	C	-	-	C	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
76 Absaroka-Beartooth	-	C	-	-	-	-	-	C	-	-	-	-	-	-	-	-	100	-	X	X	-	-	-	1
77 North Absaroka	-	-	A	-	-	C	-	C	A	-	X	X	X	-	-	-	-	-	-	-	-	-	-	3
78 Washakie	-	-	A	-	-	-	C	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	3
79 Fitzpatrick	-	-	-	-	-	-	A	-	A	-	X	X	-	-	-	-	-	-	-	-	-	-	-	3
80 Teton	-	-	A	-	-	-	-	-	-	-	-	X	-	-	-	-	00	-	-	-	-	-	-	1
81 Bridger	-	-	-	-	-	-	-	-	A	-	X	X	-	-	-	-	00	-	-	-	-	-	-	2
82 Savage Run	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
83 Lone Peak	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2
84 Lone Peak	-	-	A	-	-	A	-	A	A	-	-	-	-	-	-	-	-	-	-	X	-	-	-	3
85 Mount Zirkel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
86 Rawah	-	A	-	-	-	-	-	-	-	-	X	X	-	-	-	-	100	-	-	-	-	-	-	3
87 Flat Tops	-	-	A	-	-	-	-	-	A	-	X	X	-	-	-	-	-	-	-	-	-	-	-	1
88 Flat Tops	-	-	A	-	-	-	-	-	-	-	X	X	-	-	X	-	00	-	-	-	-	-	-	3
89 Indian Peaks	-	A	-	A	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	X	-	-	-	2
90 Eagles Nest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	1
91 Maroon Bells-Snowmass	-	-	-	-	-	-	-	-	-	-	X	X	-	X	X	-	20	-	-	-	-	-	-	3
92 Hunter Fryingpan	-	-	A	-	-	-	-	-	-	-	X	X	-	-	-	-	00	-	-	-	-	-	-	3
93 West Elk	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	100	-	-	-	-	-	-	3
94 La Garita	-	-	-	-	-	A	A	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
95 Weminuche	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
96 Weminuche	-	-	A	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
97 Sycamore Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98 Sycamore Canyon	-	-	-	-	-	-	-	A	-	-	X	-	-	X	-	-	00	-	-	-	-	-	-	1
99 Sycamore Canyon	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	100	-	-	-	-	-	-	1
100 Pine Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3

See footnotes at end of table 33, p. 46

Table 33.—(con.)

	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[c]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
101 Mazatzal	-	-	-	-	-	A	-	A	A	-	-	-	-	-	-	-		-	-	-	-	-	-	3
102 Sierra Ancha	-	-	-	-	-	A	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
103 Superstition	-	-	-	-	-	A	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
104 Mount Baldy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
105 Galiuro	-	-	-	-	-	-	-	-	A	-	X	-	-	-			-	-	-	-	-	-	-	3
106 Pusch Ridge	-	-	-	-	-	-	-	A		-	-	-	-	-	-		-	-	-	-	-	-	-	3
107 Chiricahua	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
108 Wheeler Peak	-	-	-	-	-	-	-	A	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	1
109 San Pedro Parks	-	-	A	-	-	A	A	A	A	X	X	X	-	-	X	-	UK	-	-	X	-	-	-	1
110 Chama River Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
111 Pecos	-	-	A	-	-	A	A	A	A	-	X	X	-	-	-	-	-	-	-	-	-	-	-	1
112 Pecos	-	-	A	-	C	C	C	-	C	-	X	X	-	-	X	-	100	-	-	X	-	-	-	2
113 Manzano Mountains	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
114 Sandia Mountains	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
115 Gila	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	1,2
116 White Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
117 Boundary Waters Canoe Area	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	01	-	X	-	-	X	-	-
118 Rainbow Lake	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
119 Whisker Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	1
120 Blackjack Springs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
121 Hercules Glades	C	-	A	-	-	A	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	3
122 Upper Buffalo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
123 Caney Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
124 Bristol Cliffs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
125 Lye Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	1
126 Great Gulf	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	50	-	X	-	-	-	-	1
127 Presidential-Dry River	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	X	-	X	-	-	1
128 Dolly Sods	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	00	-	-	X	-	-	-	2
129 Otter Creek	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	X	-	-	-	3
130 Beaver Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
131 James River Face	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
132 Gee Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
133 Joyce Kilmer-Slickrock	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
134 Joyce Kilmer-Slickrock	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	4
135 Cohutta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
136 Cohutta	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
137 Linville Gorge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
138 Shining Rock	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
139 Ellicott Rock	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
140 Ellicott Rock	A	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	100	-	-	-	-	-	-	1
141 Sipsey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
142 Bradwell Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
F.S. PRIMITIVE AREAS																								
143 Salmon Trinity Alps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
144 Salmon Trinity Alps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
145 High Sierra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
146 Salmon River Breaks	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
147 Salmon River Breaks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

See footnotes at end of table 33, p. 46

Table 33.—(con.)

	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[d]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
148 Idaho	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,2
149 Idaho	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	4
150 Idaho	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
151 Spanish Peaks	-	A	A	-	-	-	-	-	A	-	-	X	-	-	-	-	100	-	-	X	-	-	-	3
152 Cloud Peak	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
153 Glacier	-	-	-	-	-	-	-	C	A	-	X	X	-	-	-	-	-	-	-	-	X	-	-	3
154 Popo Agie	-	-	A	A	-	-	A	-	-	-	-	X	-	-	-	S	100	T	-	-	-	-	-	2
155 High Unitas	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	2
156 High Uintas	-	A	-	-	-	-	-	-	-	-	X	X	-	-	X	-	100	-	-	-	-	-	-	2
157 Uncompahgre	-	A	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
158 Wilson Mountains	-	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
159 Wilson Mountains	-	-	C	-	-	-	-	C	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	3
160 Blue Range	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
161 Blue Range	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
162 Gila	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
163 Aldo Leopold-Black Range	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
NPS WILDERNESS																								
164 Haleakala	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	A	-	P	-	-	-	-	X	-
165 Hawaii Volcanoes	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
166 Lava Beds	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	00	P	-	-	-	-	X	-
167 Lassen Volcanic	-	A	-	A	A	-	-	A	A	X	-	-	-	-	X	S	50	-	-	-	-	X	-	2
168 Point Reyes	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	A	-	-	-	-	-	-	X	-
169 Pinnacles	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
170 Joshua Tree	-	-	-	-	-	-	-	A	A	X	-	X	-	-	-	-	UK	P	-	-	-	-	X	-
171 Craters of the Moon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
172 Black Canyon of the Gunnison	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2
173 Great Sand Dunes	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
174 Mesa Verde	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	-	-
175 Petrified Forest	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
176 Organ Pipe Cactus	-	A	-	-	-	A	A	A	-	-	X	X	-	-	-	-	33	-	-	-	-	-	X	-
177 Saguaro	-	A	-	-	-	-	-	A	-	-	-	-	-	-	-	A	-	-	-	-	-	X	-	-
178 Chiricahua	-	-	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
179 Bandelier	-	A	-	-	-	-	-	A	-	-	X	X	X	X	X	S	75	-	-	-	-	-	-	3
180 Carlsbad Caverns	-	-	-	-	-	-	-	A	-	-	X	X	-	-	-	-	-	-	-	-	-	-	X	-
181 Guadalupe Mountains	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	A	00	T	X	-	-	-	X	-
182 Theodore Roosevelt	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
183 Badlands	-	-	-	-	A	A	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
184 Isle Royale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	00	-	-	-	-	X	-	-
185 Buffalo National River	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
186 Shenandoah	-	A	-	-	-	-	-	A	-	-	-	X	X	-	X	-	00	-	-	-	-	-	X	-
187 Everglades	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	S	00	B	-	-	-	-	-	-
188 Gulf Islands	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	T	-	-	-	-	-	-
NPS PROPOSED WILDERNESS																								
189 Mount McKinley	-	A	-	-	C	-	C	A	-	-	-	X	-	-	X	-	90	B	-	-	-	-	X	-
190 Katmai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	1
191 Glacier Bay	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	3
192 North Cascades Complex	-	A	-	-	A	-	-	A	A	-	-	-	-	-	-	A	80	P	X	-	-	X	-	-
193 Olympic	-	-	A	-	-	A	-	A	A	X	X	-	-	-	-	S	75	-	X	-	-	-	-	3
194 Mount Rainier	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	S	30	B	X	-	-	X	-	-
195 Crater Lake	-	A	A	-	-	-	-	A	-	X	X	X	X	-	X	-	00	-	-	-	-	-	-	1

See footnotes at end of table 33, p. 46

Table 33.—(con.)

	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[d]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
196 Yosemite	-	A	-	-	-	-	-	-	A	X	X	X	-	-	-	-	-	-	-	-	X	X	-	3
197 Sequoia-Kings Canyon	-	A	-	A	-	-	-	-	A	X	X	-	-	X	X	S	10	P	-	X	-	-	-	3
198 Death Valley	-	-	-	-	-	A	-	A	A	-	X	-	-	-	-	-	-	P	-	-	-	-	X	-
199 Glacier	-	A	-	A	A	A	-	A	-	X	X	X	X	-	X	A	00	P	-	-	-	X	-	-
200 Yellowstone	-	-	-	A	-	A	A	-	A	-	-	-	-	-	-	S	40	-	-	-	-	X	-	2
201 Grand Teton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202 Dinosaur	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	S	-	-	-	X	-	-	-	1
203 Rocky Mountain	-	A	-	-	A	A	-	A	A	-	-	-	-	-	-	A	00	-	X	-	-	X	-	-
204 Colorado	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X	-
205 Zion	-	A	A	-	-	A	-	A	A	-	X	-	-	-	-	-	100	-	X	-	-	-	X	-
206 Cedar Breaks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2
207 Bryce Canyon	-	A	-	-	-	A	-	-	A	-	-	-	-	-	-	A	-	-	-	-	-	-	X	4
208 Capitol Reef	-	-	-	-	-	-	A	A	A	-	-	X	-	-	-	-	00	-	-	X	-	-	-	1
209 Canyonlands	-	A	-	-	-	-	-	A	-	-	X	-	-	-	-	-	-	-	-	-	-	X	-	-
210 Arches	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X	1
211 Cumberland Gap	-	A	-	-	A	-	-	A	A	-	-	-	-	-	-	S	-	-	-	-	-	X	-	-
212 Great Smoky Mountains	-	A	-	-	-	A	-	A	-	-	-	-	-	-	-	A	90	-	-	X	-	-	-	2
F&WS WILDERNESS																								
213 San Juan Islands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	00	P	-	-	-	-	X	-
214 Red Rocks Lakes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	X	-
215 Crab Orchard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
216 Mingo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
217 Wichita Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
218 Lacassine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
219 Breton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	T	-	-	-	-	-	-
220 Monomy	A	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
221 Great Swamp	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
222 Cape Romain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	X	-
223 Blackbeard Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
224 Wolf Island	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
225 Okefenokee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	P	-	-	-	X	-	1
226 Cedar Keys	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	X	-
227 Chassahowitzka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	X	-
228 Passage Key	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
229 J.N. "Ding" Darling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
F&WS PROPOSED WILDERNESS																								
230 Aleutian Islands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	X	UK
231 Nunivak	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
232 Kenai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
233 Kenai Lakes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
234 Hart Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
235 Havasu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
236 Charles M. Russell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
237 Desert	-	-	-	A	-	-	-	-	-	-	X	X	-	-	-	-	100	-	-	-	-	-	-	4
238 Kofa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
239 Cabeza Prieta	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	P	-	-	-	-	-	2
240 Missiquoi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
241 Parker River	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	-	-	X	-

See footnotes at end of table 33, p. 46

Table 33.—(con.)

	Packstock Restrictions[a]									Camping Regulations-Camping Prohibited in:										Wood Fire Restrictions				
	Stock prohibited	Area or trail prohibitions	Prohibited near waterbodies	Seasonal prohibitions	Must use stock camps	Prohibited in camp areas	Grazing by permit only	Must carry feed	Stock-restraint prohibitions	Selected ecosystems	Near waterbodies	Near trails	Near other camps	Closed campsites	Closed areas	Camp only at designated sites[b]	Campsite closures (% temporary)[c]	Area closures[d]	Rehabilitation program	Fires discouraged	Prohibited in sub-alpine areas	Only at designated sites	Prohibited	Impromptu fire ring policy[e]
BLM PRIMITIVE AREAS																								
242 Chemise Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
243 Humbug Spires	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
244 Beartrap Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
245 Centennial Mountains	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
246 Scab Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
247 Powderhorn	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	2
248 Paria Canyon	C	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	1
249 Dark Canyon	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	1
250 Grand Gulch	-	-	-	-	-	A	-	A	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-
251 Paiute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
252 Aravaipa Canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	100	-	-	-	-	-	-	2

a (A)-applies to all users; (C)-applies for only commercial users (outfitters, packers, etc.).
b (A)-applies throughout area; (S)-applies in selected areas only.
c Percent of closures that are temporary; (-)-no campsites closed.
d (P)-closed permanently; (T)-closed temporarily; (B)-both (some permanent, some temporary).
e (1)-remove all rings; (2)-leave one ring per camp; (3)-remove rings from "undesirable" camps; (4)-no ring removal.

Table 34.—Minimum impact, use dispersal, nonconforming uses, planning and administration

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
F.S. WILDERNESS																						
1 Pasayten	X	D	H	-	-	H	P	H	-	-	-	H	H	-	H	-	P	-	H	P	-	10
2 Glacier Peak	X	D	H	-	-	H	H	P	-	-	H	-	H	-	P	-	P	-	H	-	-	9
3 Glacier Peak	X	D	H	-	-	H	-	-	-	-	-	-	H	-	-	-	P	-	H	P	-	4
4 Alpine Lakes	X	-	-	-	-	-	H	-	-	-	-	H	P	-	-	-	P	-	P	P	-	14
5 Alpine Lakes	X	D	-	-	-	-	-	-	-	-	-	H	H	-	H	-	P	-	P	P	-	6
6 Goat Rocks	X	B	-	-	-	-	-	-	-	-	-	-	H	-	-	-	P	-	P	-	-	1
7 Goat Rocks	X	D	-	-	-	P	-	-	P	-	-	-	-	-	H	-	P	-	P	-	-	4
8 Mount Adams	X	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	P	-	-	H	-	6
9 Wenaha-Tucannon	X	-	H	-	-	P	-	H	-	-	-	-	-	-	H	H	-	-	P	P	-	10
10 Eagle Cap	X	B	P	-	P	H	H	H	-	-	-	P	P	-	H	-	-	-	H	P	-	15
11 Hells Canyon	-	-	H	-	-	H	-	H	-	-	H	H	-	H	H	-	H	H	P	P	-	1
12 Hells Canyon	X	D	-	-	-	-	H	H	H	-	-	-	H	-	-	-	-	H	P	P	-	3
13 Strawberry Mountain	X	D	-	-	-	-	-	H	-	-	-	-	P	-	-	H	-	-	H	P	-	4
14 Mount Hood	X	D	-	-	-	-	-	H	-	-	-	-	H	-	-	-	P	-	P	-	-	4
15 Mount Jefferson	X	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	H	-	-	1
16 Mount Jefferson	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	H	-	-	5
17 Mount Jefferson	X	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	H	P	-	2
18 Mount Washington	X	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	-	H	-	2
19 Mount Washington	X	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	P	-	-	0
20 Three Sisters	X	D	H	-	-	H	P	H	-	-	-	-	H	-	H	-	H	-	H	H	-	5
21 Three Sisters	X	-	P	-	-	H	P	-	-	-	-	-	H	-	-	-	-	-	H	H	-	3
22 Diamond Peak	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	P	P	-	1
23 Diamond Peak	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	P	-	-	2
24 Mountain Lake	X	B	-	-	-	-	-	H	-	-	-	-	H	-	-	-	-	-	P	P	-	1
25 Gearhart Mountain	X	D	P	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	H	-	-	1
26 Wild Rogue	X	D	-	-	H	H	H	H	P	-	H	-	-	-	-	-	-	H	P	-	-	6
27 Kalmiopsis	X	-	-	-	-	H	H	H	-	P	-	-	H	-	-	-	-	-	P	P	-	2
28 Marble Mountain	X	B	H	-	-	H	-	H	-	-	-	H	H	-	-	-	H	H	H	P	-	5
29 South Warner	X	-	H	-	-	H	-	-	-	-	-	H	H	-	-	-	-	-	P	P	-	1
30 Thousand Lakes	X	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	H	-	-	1
31 Caribou	-	-	H	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	H	P	-	2
32 Yolla Bolly-Middle Eel	X	-	-	-	H	-	H	H	-	-	-	H	H	-	-	-	-	-	H	P	-	4
33 Desolation	X	B	H	-	-	H	H	-	-	-	-	P	H	-	-	-	H	-	H	P	-	4
34 Mokelumne	X	D	H	-	-	-	H	H	-	-	-	H	H	-	-	-	-	-	P	P	-	4
35 Mokelumne	X	D	H	-	-	-	-	H	-	-	-	-	H	-	-	-	-	-	P	P	-	0
36 Emigrant	X	B	P	H	P	H	-	P	-	-	-	H	P	-	-	-	H	-	P	H	-	6-8
37 Hoover	X	B	H	-	-	H	H	-	-	-	-	H	H	-	-	-	-	-	H	H	-	4-5
38 Hoover	X	B	-	-	-	-	H	H	-	-	-	H	H	-	-	-	-	-	H	P	-	1
39 Minarets	X	D	P	-	-	-	H	H	-	-	-	-	H	-	H	-	-	-	P	P	-	2
40 Minarets	X	B	H	-	-	H	H	H	H	-	-	H	H	-	H	-	H	-	H	P	-	9
41 Kaiser	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	P	-	2
42 John Muir	X	D	H	-	-	H	H	H	-	-	-	-	H	-	-	-	-	-	H	P	-	24
43 John Muir	X	B	H	-	H	H	H	H	-	-	-	H	H	-	H	-	H	-	H	P	-	20
44 Golden Trout	X	-	H	-	P	H	H	H	H	-	-	H	-	-	-	-	-	-	P	-	-	4
45 Golden Trout	X	D	H	H	P	H	-	H	-	-	H	-	H	-	H	H	H	H	P	P	-	3

See footnotes at end of table 34, p.52

Table 34.—(con.)

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
46 Domeland	-	-	H	-	-	H	H	H	-	-	-	-	-	-	-	-	-	-	P	P	-	1
47 Ventana	X	D	H	-	H	H	H	H	-	-	-	-	H	-	H	H	-	-	P	-	-	19
48 Santa Lucia	-	-	H	H	H	H	H	-	-	-	-	-	-	-	-	-	-	-	P	-	-	0
49 San Rafael	X	O	H	-	H	H	-	H	-	-	-	-	H	-	-	-	-	-	P	-	-	3
50 San Gabriel	X	O	-	-	-	H	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	3
51 Cucamonga	X	D	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	H	P	-	3
52 San Gorgonio	-	D	-	-	-	-	-	H	-	-	-	-	-	-	H	-	-	-	H	P	-	5
53 San Jacinto	-	B	-	-	H	H	-	H	-	-	-	-	-	-	H	-	H	-	H	-	-	4
54 Aqua Tibia	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	3
55 Jarbidge	-	D	H	-	-	-	H	H	-	-	-	-	-	-	-	-	-	-	H	P	-	2
56 Selway-Bitterroot	X	D	-	-	-	H	-	H	-	-	H	-	H	-	H	-	-	H	H	H	-	8
57 Selway-Bitterroot	X	B	-	-	H	H	H	H	-	-	P	H	H	-	H	-	-	P	H	H	-	10
58 Selway-Bitterroot	X	D	-	H	H	H	H	H	-	-	H	H	H	-	H	-	-	H	H	P	-	7
59 Selway-Bitterroot	X	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	P	-	0
60 Sawtooth	X	B	H	-	-	H	P	H	-	P	-	-	H	-	-	-	-	-	H	H	-	13
61 Gospel Hump	X	O	P	-	H	H	P	H	P	-	-	-	H	-	P	-	-	H	-	-	-	3
62 Cabinet Mountains	X	D	-	-	-	H	P	-	-	-	-	-	-	-	H	-	-	-	H	P	-	4
63 Mission Mountains	-	O	-	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	H	P	-	1
64 Great Bear	X	-	-	-	-	H	P	-	-	-	H	-	-	-	H	-	-	H	P	P	-	1
65 Bob Marshall	X	D	-	-	-	H	-	-	-	-	-	-	H	-	-	-	H	H	H	P	-	4
66 Bob Marshall	X	D	H	-	-	H	-	-	-	-	H	-	-	-	-	-	-	-	H	P	-	7
67 Scapegoat	-	D	-	-	H	H	-	-	-	-	-	-	-	-	H	-	-	-	-	H	-	2
68 Scapegoat	-	B	H	-	-	H	H	-	-	-	-	-	-	-	H	-	H	-	P	H	-	7
69 Scapegoat	X	D	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	P	P	-	1
70 Gates of the Mountain	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	2
71 Welcome Creek	-	O	-	-	-	P	P	-	-	-	-	-	-	-	-	-	-	-	P	P	-	1
72 Anaconda-Pintler	X	D	-	-	-	-	-	-	-	-	-	-	H	-	H	-	H	-	H	P	-	1
73 Anaconda-Pintler	X	D	H	-	-	-	H	-	-	-	-	-	H	-	-	-	-	-	H	P	-	1
74 Anaconda-Pintler	-	-	H	-	-	H	-	H	-	-	-	-	H	-	H	-	-	-	H	P	-	2
75 Absaroka-Beartooth	X	D	H	-	H	H	H	H	-	-	H	-	H	-	-	-	-	-	-	P	-	8
76 Absaroka-Beartooth	X	D	-	P	-	P	P	-	-	-	-	H	H	-	H	-	-	-	P	P	-	3
77 North Absaroka	X	D	H	-	-	-	H	H	-	-	-	-	-	-	-	-	-	-	P	H	-	6
78 Washakie	X	D	H	H	-	H	H	H	-	-	-	-	H	-	-	-	-	-	H	H	-	8
79 Fitzpatrick	X	D	H	-	P	H	-	H	-	-	-	-	H	-	H	-	-	-	P	P	-	2
80 Teton	-	D	P	-	-	H	H	H	-	-	-	-	H	-	H	-	-	-	H	H	-	3
81 Bridger	X	D	P	-	-	H	H	-	-	H	-	H	H	-	-	-	-	-	H	P	-	5
82 Savage Run	-	-	P	-	-	H	P	H	-	-	-	H	-	-	-	-	-	-	P	-	-	1
83 Lone Peak	X	D	-	-	-	-	-	-	H	-	-	H	H	-	H	-	-	-	P	H	-	3
84 Lone Peak	X	D	H	-	-	H	H	-	P	-	-	H	H	-	H	-	-	-	P	H	-	1
85 Mount Zirkel	-	D	H	-	-	-	H	-	-	-	-	-	H	-	-	-	-	-	P	P	-	2
86 Rawah	X	-	-	-	-	H	-	H	-	-	-	-	H	-	-	-	-	-	P	P	-	10
87 Flat Tops	X	-	H	-	-	-	-	H	-	-	-	H	H	-	-	-	-	-	H	H	-	2
88 Flat Tops	X	D	H	-	H	H	-	-	-	-	-	H	H	-	-	-	-	-	H	P	-	7
89 Indian Peaks	X	B	H	-	H	H	H	H	-	-	-	H	H	-	H	-	P	-	P	P	-	7
90 Eagles Nest	X	D	H	-	H	P	-	-	-	P	-	-	H	-	H	-	-	-	P	P	-	14

See footnotes at end of table 34, p. 52

Table 34.—(con.)

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
91 Maroon Bells-Snowmass	X	-	H	-	-	-	P	P	-	-	-	H	H	-	H	-	-	-	P	P	-	6
92 Hunter Fryingpan	-	-	-	-	-	-	-	H	-	-	-	-	H	-	-	-	-	-	H	-	-	3
93 West Elk	X	-	P	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	H	-	0
94 La Garita	X	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	P	-	1
95 Weminuche	X	D	H	H	H	H	P	-	-	-	-	P	H	-	-	-	-	-	P	P	-	6
96 Weminuche	-	D	H	-	-	H	H	H	-	-	-	-	H	-	H	-	-	-	P	P	-	1
97 Sycamore Canyon	-	D	-	-	-	-	-	P	-	-	-	-	-	H	-	-	-	-	H	P	-	1
98 Sycamore Canyon	-	-	H	-	-	H	H	P	-	-	-	H	-	-	-	-	-	-	H	P	-	1
99 Sycamore Canyon	X	-	H	-	-	H	H	P	-	-	-	H	-	-	H	-	-	-	H	P	-	1
100 Pine Mountain	X	D	H	H	H	-	-	H	-	-	-	-	-	-	-	-	-	-	H	P	-	1
101 Mazatzal	-	O	P	P	-	P	P	P	-	P	-	P	-	-	-	-	-	P	H	P	-	4
102 Sierra Ancha	X	D	P	-	-	-	H	P	-	-	-	H	-	-	-	-	-	-	H	P	-	0
103 Superstition	X	-	P	H	-	-	P	H	-	-	-	P	-	-	-	-	-	-	H	P	-	4
104 Mount Baldy	X	D	P	-	-	-	-	H	-	-	-	-	-	-	-	H	-	-	H	P	-	2
105 Galiuro	X	-	H	-	-	H	H	H	-	-	-	H	-	-	-	-	-	-	H	H	-	0
106 Pusch Ridge	-	-	-	-	-	-	H	H	-	-	-	H	-	-	H	H	-	-	P	P	-	4
107 Chiricahua	-	-	H	-	-	H	-	H	-	-	-	H	-	-	H	H	-	-	H	P	-	3
108 Wheeler Peak	X	B	-	-	-	-	-	-	-	-	-	H	H	-	-	-	-	-	H	-	-	1
109 San Pedro Parks	-	D	P	-	-	H	-	H	-	-	-	P	H	-	-	-	-	-	H	H	-	4
110 Chama River Canyon	X	-	P	-	-	H	H	H	-	P	-	H	-	-	H	-	-	-	H	-	-	1
111 Pecos	X	D	H	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	H	H	-	1
112 Pecos	X	D	P	-	-	H	H	-	-	-	-	-	H	-	-	-	-	-	H	P	-	5
113 Manzano Mountains	X	-	H	-	H	-	H	H	-	-	-	-	-	H	-	-	-	-	P	-	-	0
114 Sandia Mountains	-	-	-	-	-	-	H	H	-	-	-	-	-	-	-	-	-	-	P	-	-	1
115 Gila	X	D	H	-	-	H	H	P	-	-	-	H	H	-	H	-	-	-	H	H	-	7
116 White Mountain	X	D	H	-	-	H	P	-	-	P	-	-	-	-	-	-	-	-	H	P	-	1
117 Boundary Waters Canoe Area	X	O	-	-	P	P	-	H	P	-	-	H	P	-	P	-	-	-	H	P	-	45
118 Rainbow Lake	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	P	-	-	1
119 Whisker Lake	-	-	-	H	H	H	-	-	-	-	-	-	H	-	-	-	-	-	P	-	-	1
120 Blackjack Springs	-	-	-	-	-	-	-	H	-	-	-	-	H	H	-	-	-	-	P	-	-	0
121 Hercules Glades	X	D	H	-	-	-	-	-	-	-	-	H	-	-	H	-	-	-	P	-	-	1
122 Upper Buffalo	X	-	H	H	-	-	H	H	-	H	-	-	-	-	-	-	-	H	P	-	-	0
123 Caney Creek	-	-	-	-	-	-	H	-	-	-	-	-	-	H	-	-	-	-	P	-	-	1
124 Bristol Cliffs	-	-	-	-	H	-	-	H	-	-	-	-	-	-	-	-	-	-	P	-	-	0
125 Lye Brook	-	B	-	-	H	H	-	H	-	-	-	-	H	-	-	-	H	-	P	-	-	2
126 Great Gulf	-	B	-	-	-	-	-	-	-	-	-	-	-	-	H	-	H	-	H	-	-	5
127 Presidential-Dry River	-	B	-	-	-	H	-	-	-	-	-	-	-	-	H	-	-	-	P	-	-	2
128 Dolly Sods	X	B	H	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	P	-	-	2
129 Otter Creek	X	D	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	1
130 Beaver Creek	X	-	-	-	-	-	P	H	-	-	-	-	H	-	H	-	-	-	P	-	-	0
131 James River Face	-	-	-	-	-	P	-	P	-	-	-	-	-	-	-	-	P	-	H	-	-	1
132 Gee Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	0
133 Joyce Kilmer-Slickrock	X	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	P	-	-	1
134 Joyce Kilmer-Slickrock	X	D	-	-	-	-	-	-	-	-	-	-	H	-	-	-	P	-	H	-	-	2
135 Cohutta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	0

See footnotes at end of table 34, p. 52

Table 34.—(con.)

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
136 Cohutta	X	D	-	H	P	H	H	-	-	P	-	-	-	-	-	-	-	-	H	-	-	2
137 Linville Gorge	X	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	H	H	-	-	2
138 Shining Rock	X	O	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	H	0
139 Ellicott Rock	-	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	H	H	-	-	0
140 Ellicott Rock	-	-	-	-	-	-	-	H	-	-	-	-	H	-	-	-	-	H	P	H	-	2
141 Sipsey	-	-	-	H	H	H	H	-	-	-	-	-	-	-	-	H	-	H	H	H	-	0
142 Bradwell Bay	-	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	P	-	1
F.S. PRIMITIVE AREAS																						
143 Salmon Trinity Alps	-	B	H	P	P	-	-	H	-	-	-	H	H	-	-	-	H	-	-	-	-	1
144 Salmon Trinity Alps	X	D	P	P	H	P	P	P	-	-	-	H	P	-	H	-	-	-	H	-	-	6
145 High Sierra	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
146 Salmon River Breaks	X	-	-	H	H	-	P	H	P	-	H	-	H	-	-	-	-	P	H	P	-	6
147 Salmon River Breaks	X	B	-	-	-	P	-	H	P	-	-	-	P	-	H	H	-	P	H	P	-	1
148 Idaho	X	-	-	-	P	H	P	H	-	P	P	-	H	-	H	-	-	H	H	P	-	1
149 Idaho	X	-	-	-	P	P	P	H	-	H	H	-	H	-	H	-	-	H	H	P	-	14
150 Idaho	-	D	H	H	H	H	H	H	H	-	H	-	H	H	H	-	-	H	P	P	-	2
151 Spanish Peaks	X	D	-	-	H	H	H	H	-	-	-	-	-	-	H	-	-	-	H	P	-	3
152 Cloud Peak	-	-	H	-	-	-	-	P	-	-	-	H	P	-	-	-	-	-	-	P	-	7
153 Glacier	X	D	H	-	-	-	-	-	-	H	-	-	-	-	H	-	-	-	P	-	H	1
154 Popo Agie	X	B	P	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	P	-	4
155 High Unitas	X	B	H	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	P	-	-	5
156 High Uintas	X	D	P	-	-	H	H	H	H	-	-	P	H	-	-	-	-	-	P	P	-	10
157 Uncompahgre	-	-	H	-	H	H	P	H	-	P	-	-	H	H	H	-	-	-	-	-	-	0
158 Wilson Mountains	-	-	P	-	H	H	P	-	-	H	-	H	-	-	-	-	-	-	-	-	-	1
159 Wilson Mountains	X	B	H	-	-	H	P	H	-	-	-	-	-	-	-	-	-	H	P	H	-	1
160 Blue Range	-	-	P	P	H	-	P	H	-	P	-	H	H	-	-	-	-	-	-	H	-	0
161 Blue Range	-	-	H	-	-	-	-	H	-	-	-	-	-	H	-	-	-	-	P	H	-	0
162 Gila	X	D	H	-	-	-	-	H	-	-	-	H	H	-	-	-	-	-	H	P	-	7
163 Aldo Leopold-Black Range	-	D	P	P	-	H	H	P	-	P	-	H	H	-	H	-	-	-	-	P	-	1
NPS WILDERNESS																						
164 Haleakala	X	-	-	-	H	H	-	H	-	-	-	H	-	-	H	H	-	-	H	-	-	5
165 Hawaii Volcanoes	X	D	-	-	-	H	-	H	-	-	-	P	-	H	H	-	-	-	H	H	-	3
166 Lava Beds	-	-	H	-	-	-	-	H	-	-	-	-	-	H	H	H	-	-	H	H	H	8
167 Lassen Volcanic	X	-	-	-	-	H	-	H	-	-	-	-	H	-	-	-	H	-	H	H	-	2
168 Point Reyes	-	-	-	-	H	-	-	H	H	-	-	H	H	-	H	-	-	-	P	P	-	5
169 Pinnacles	-	-	-	-	-	-	-	H	-	-	-	H	-	-	H	-	-	-	-	P	H	6
170 Joshua Tree	X	-	-	-	H	H	H	H	-	-	H	H	-	H	H	-	-	-	-	P	-	3
171 Craters of the Moon	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	-	1
172 Black Canyon of the Gunnison	X	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	-	3
173 Great Sand Dunes	X	-	-	P	-	-	-	-	-	P	-	-	-	-	H	-	-	-	P	P	-	15
174 Mesa Verde	-	-	-	-	-	-	-	H	-	-	-	-	-	-	H	-	-	-	-	P	-	0
175 Petrified Forest	X	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	H	H	-	1
176 Organ Pipe Cactus	-	D	H	-	-	H	-	P	-	-	-	-	-	P	H	H	-	-	-	H	-	0
177 Saguaro	X	D	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	H	H	-	1
178 Chiricahua	-	-	-	-	H	-	-	H	-	-	-	-	-	-	-	H	-	-	H	P	-	4

See footnotes at end of table 34, p.52

Table 34.—(con.)

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
179 Bandelier	X	D	-	-	-	-	-	H	-	-	-	H	-	-	H	-	-	-	P	-	P	0
180 Carlsbad Caverns	X	D	-	-	-	P	-	H	-	-	-	-	-	-	H	-	-	-	-	P	H	1
181 Guadalupe Mountains	X	D	-	-	-	P	-	H	-	-	-	H	-	-	H	-	-	-	-	P	H	3-5
182 Theodore Roosevelt	-	-	-	-	-	-	-	-	-	-	-	H	-	-	H	-	-	H	P	P	-	12
183 Badlands	X	-	H	P	-	P	H	H	-	-	-	P	-	-	H	-	-	-	P	P	-	1
184 Isle Royale	X	D	-	-	-	H	-	H	H	-	H	-	-	H	H	H	-	-	P	H	-	26
185 Buffalo National River	-	-	P	P	P	P	H	H	-	-	-	H	-	H	-	-	-	H	-	P	H	14
186 Shenandoah	X	D	-	-	-	-	-	H	-	-	-	-	-	-	-	-	H	-	P	P	-	10-20
187 Everglades	X	D	-	-	-	-	-	H	P	-	-	-	-	-	P	-	-	-	P	H	H	15
188 Gulf Islands	-	-	-	-	-	-	-	H	-	-	-	-	-	-	H	-	-	-	P	H	-	2
NPS PROPOSED WILDERNESS																						
189 Mount McKinley	X	D	-	-	-	H	P	H	-	P	P	-	-	-	H	-	-	-	H	P	-	4
190 Katmai	X	B	-	-	-	H	-	H	-	-	-	-	-	H	H	-	-	-	P	-	-	2
191 Glacier Bay	X	D	-	-	-	-	P	H	H	-	-	-	-	-	H	-	-	-	P	-	-	6
192 North Cascades Complex	X	D	-	-	-	H	H	-	-	-	-	-	H	-	H	H	P	H	H	P	-	11
193 Olympic	X	D	-	-	-	P	-	-	-	-	-	-	P	H	H	H	-	-	H	P	-	84
194 Mount Rainier	X	-	-	-	-	-	H	-	-	-	-	-	-	-	H	H	H	-	H	H	-	18
195 Crater Lake	X	D	P	-	-	-	-	-	-	-	-	H	-	-	H	H	H	-	P	H	H	3
196 Yosemite	X	-	-	-	-	P	H	H	-	-	-	-	P	-	H	H	H	H	H	H	-	17
197 Sequoia-Kings Canyon	X	B	H	H	H	H	H	H	-	-	-	P	H	-	H	H	H	H	H	H	H	25
198 Death Valley	X	-	-	-	-	H	-	H	-	-	-	-	-	-	H	-	-	-	-	H	-	3
199 Glacier	X	B	-	-	-	H	H	H	H	-	-	-	-	-	-	H	H	H	H	H	-	43
200 Yellowstone	X	D	-	-	-	-	-	H	P	-	-	-	-	-	H	H	-	-	P	H	-	10
201 Grand Teton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202 Dinosaur	-	-	P	P	P	-	-	H	-	-	-	-	-	-	H	H	-	H	P	P	-	2
203 Rocky Mountain	X	-	-	-	-	H	-	H	-	-	-	P	-	-	H	H	-	H	H	H	-	20
204 Colorado	-	-	-	-	-	-	-	P	-	-	-	-	-	-	P	-	-	-	-	-	-	0
205 Zion	X	D	-	-	-	H	H	H	-	-	-	H	-	-	H	H	-	-	-	P	-	2
206 Cedar Breaks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
207 Bryce Canyon	X	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-	1
208 Capitol Reef	-	-	P	-	-	-	P	H	-	-	-	-	-	-	H	H	-	-	H	P	-	2
209 Canyonlands	X	-	H	-	-	-	H	H	-	-	-	-	-	-	-	-	-	H	-	-	-	15
210 Arches	X	D	P	-	-	-	P	H	-	H	-	-	-	H	-	H	-	-	-	P	-	0
211 Cumberland Gap	X	D	-	-	-	H	-	-	-	-	-	-	-	-	H	-	-	-	-	P	-	10
212 Great Smoky Mountains	X	B	-	-	P	H	-	H	-	-	-	-	-	-	-	H	H	-	-	P	-	25
F&WS WILDERNESS																						
213 San Juan Islands	-	-	-	-	-	H	-	-	H	-	-	-	-	-	-	-	-	-	H	-	-	0
214 Red Rocks Lakes	-	-	H	H	-	-	-	-	H	-	-	H	-	-	-	-	-	-	P	H	H	0
215 Crab Orchard	-	-	-	-	-	-	-	-	-	P	-	H	-	-	-	H	-	-	P	H	-	0
216 Mingo	-	-	-	-	-	-	-	H	-	-	-	P	-	-	-	H	-	-	H	-	-	0
217 Wichita Mountains	-	-	-	-	-	-	-	-	-	-	-	H	-	-	-	H	-	-	H	H	H	0
218 Lacassine	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	0
219 Breton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
220 Monomy	-	-	-	-	-	H	-	-	-	-	-	H	-	-	-	-	-	-	P	H	-	0

See footnotes at end of table 34, p 52

Table 34.—(con.)

	Minimum impact program	Use-dispersal program[a]	Grazing allotments[b]	Private in-holdings[b]		Cabins[b]	Mineral claims[b]	Cultural sites[b]	Allowed motorboat use[b]	Allowed motor vehicle use[b]	Airfields[b]	Water impoundments[b]	Fish stocking[b]	Electronic sites[b]	Research projects or installations[b]	Research Natural Areas[b]	National Scenic Trails[b]	Wild Rivers[b]	Have management plans[c]	Have plans allowing some natural fires to burn[d]	Use prescribed burning	Personnel (in area or at trailheads - number)
				For commercial use	For personal use																	
221 Great Swamp	-	D	-	-	-	-	-	H	-	-	-	H	-	H	H	H	-	-	H	-	-	2
222 Cape Romain	-	-	-	-	-	-	-	H	H	-	P	-	-	-	H	-	-	-	P	-	-	0
223 Blackbeard Island	-	-	-	-	-	-	-	H	H	-	-	-	-	-	H	H	-	-	-	H	-	4
224 Wolf Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	-	0
225 Okefenokee	X	-	-	-	-	-	-	H	H	-	-	-	-	-	H	H	-	-	P	P	H	0
226 Cedar Keys	-	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-	-	-	-	-	-	1
227 Chassahowitzka	-	-	-	-	P	P	-	-	H	-	-	-	-	H	-	-	-	-	-	H	-	2
228 Passage Key	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
229 J.N. "Ding" Darling	-	-	-	-	-	-	-	H	P	-	-	-	-	-	-	H	-	-	-	P	-	0
F&WS PROPOSED WILDERNESS																						
230 Aleutian Islands	-	-	-	H	H	P	-	H	H	-	-	-	-	-	H	H	-	-	-	P	-	0
231 Nunivak	-	-	-	-	H	H	-	H	H	-	H	-	-	-	H	-	-	-	-	-	-	0
232 Kenai	-	-	-	-	H	H	-	H	H	H	H	-	H	-	H	H	-	-	-	P	-	0
233 Kenai Lakes	-	-	-	-	-	H	-	H	H	-	H	-	H	-	H	H	-	-	P	P	-	3
234 Hart Mountain	-	-	H	H	-	-	-	H	-	-	-	H	-	H	-	H	-	-	-	-	H	0
235 Havasu	-	-	-	-	-	-	P	-	H	-	-	-	-	-	-	-	-	-	P	P	-	0
236 Charles M. Russell	-	-	H	P	P	P	-	H	-	-	-	H	-	-	-	-	-	H	P	P	-	0
237 Desert	-	D	-	-	-	-	H	H	-	H	-	H	-	H	-	H	-	-	-	P	-	1
238 Kofa	-	-	P	-	-	H	H	H	-	-	-	H	-	H	H	-	-	-	-	-	-	0
239 Cabeza Prieta	-	-	P	-	-	H	H	H	-	H	-	H	-	H	-	H	-	-	-	-	-	0
240 Missiquoi	-	-	-	-	-	H	-	-	-	H	-	-	-	-	-	H	-	-	-	-	-	0
241 Parker River	-	-	-	-	H	-	-	-	-	-	-	-	-	-	H	H	-	-	-	-	-	0
BLM PRIMITIVE AREAS																						
242 Chemise Mountain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
243 Humbug Spires	-	-	H	-	P	P	-	H	-	-	-	-	-	-	-	-	-	-	P	-	-	0
244 Beartrap Canyon	-	-	-	-	-	H	-	H	-	-	-	-	-	H	-	-	-	-	P	H	-	0
245 Centennial Mountains	-	-	P	-	-	-	P	-	-	-	-	-	H	-	P	-	H	-	P	-	-	0
246 Scab Creek	-	-	H	-	-	-	-	H	-	-	-	-	H	-	-	-	-	-	H	P	-	1
247 Powderhorn	X	D	P	H	-	-	-	H	-	H	-	H	P	-	-	-	-	-	H	H	-	2
248 Paria Canyon	X	-	P	-	-	H	H	H	-	-	-	-	H	H	-	-	-	-	H	P	-	1
249 Dark Canyon	X	D	-	-	-	-	H	P	-	-	-	-	-	-	-	-	-	-	-	H	-	4
250 Grand Gulch	X	D	-	-	-	-	H	H	-	-	-	-	-	-	-	-	-	H	H	H	-	5
251 Paiute	-	-	P	-	-	-	H	H	-	-	-	-	-	-	-	-	-	-	H	P	-	0
252 Aravaipa Canyon	X	D	P	-	-	-	-	H	-	H	-	-	-	-	-	-	-	-	P	-	-	4

[a] (D)-dispersal within area; (O)-dispersal to other areas; (B)-dispersal both within and to other areas; (-)-no dispersal program.
[b] (H)-have in area; (P)-have and is a problem; (-)-do not have in area.
[c] (H)-have management plan; (P)-management plan being prepared or planned; (-)-no plan in preparation.
[d] (H)-plan allowing some natural fires to burn exists now; (P)-working toward plan; (-)-no natural fires allowed to burn.

APPENDIX B—INDEX TO AREAS SURVEYED

NDEX 1. AREAS REPORTED IN DETAIL

rea	Number	Agency	Forest	State
bsaroka-Beartooth	75	FS	Gallatin	MT
bsaroka-Beartooth	76	FS	Custer	MT
ldo Leopold-Black Range	163	FS	Gila	NM
leutian Islands	230	FWS	—	AK
lpine Lakes	4	FS	Mt. Baker-Snoqualmie	WA
lpine Lakes	5	FS	Wenatchee	WA
naconda-Pintler	72	FS	Bitterroot	MT
naconda-Pintler	73	FS	Deerlodge	MT
naconda-Pintler	74	FS	Beaverhead	MT
gua Tibia	54	FS	Cleveland	CA
ravaipa Canyon	252	BLM	—	AZ
rches	210	NPS	—	UT
adlands	183	NPS	—	SD
andelier	179	NPS	—	NM
eartrap Canyon	244	BLM	—	MT
eaver Creek	130	FS	Daniel Boone	KY
lackbeard Island	223	FWS	—	GA
lack Canyon of the Gunnison	172	NPS	—	CO
lackjack Springs	120	FS	Nicolet	WI
lue Range	160	FS	Apache	AZ
lue Range	161	FS	(Gila) Apache	NM
ob Marshall	65	FS	Flathead	MT
ob Marshall	66	FS	Lewis and Clark	MT
oundary Waters Canoe Area	117	FS	Superior	MN
radwell Bay	142	FS	Apalachicola	FL
reton	219	FWS	—	LA
ridger	81	FS	Bridger-Teton	WY
ristol Cliffs	124	FS	Green Mountain	VT
ryce Canyon	207	NPS	—	UT
uffalo National River	185	NPS	—	AR
abeza Prieta	239	FWS	—	AZ
abinet Mountains	*	FS	Kaniksu	MT
abinet Mountains	62	FS	Kootenai	MT
aney Creek	123	FS	Ouchita	AR
anyonlands	209	NPS	—	UT
ape Romain	222	FWS	—	SC
apitol Reef	208	NPS	—	UT
aribou	31	FS	Lassen	CA
arlsbad Caverns	180	NPS	—	NM
edar Breaks	206	NPS	—	UT
edar Keys	226	FWS	—	FL
entennial Mountains	245	BLM	—	MT
hama River Canyon	*	FS	Carson	NM
hama River Canyon	110	FS	Santa Fe	NM
harles M. Russell	236	FWS	—	MT
hassahowitzka	227	FWS	—	FL
hemise Mountain	242	BLM	—	CA
hiricahua	178	NPS	—	AZ
hiricahua	107	FS	Coronado	AZ
loud Peak	152	FS	Bighorn	WY
ohutta	135	FS	Cherokee	TN
ohutta	136	FS	Chattahoochee	GA
olorado	204	NPS	—	CO
rab Orchard	215	FWS	—	IL
rater Lake	195	NPS	—	OR
raters of the Moon	171	NPS	—	ID
ucamonga	51	FS	San Bernardino	CA
umberland Gap	211	NPS	—	KY
ark Canyon	249	BLM	—	UT
eath Valley	198	NPS	—	CA
esert	237	FWS	—	NV
esolation	33	FS	Eldorado	CA
iamond Peak	22	FS	Willamette	OR
iamond Peak	23	FS	Deschutes	OR
inosaur	202	NPS	—	CO/UT
olly Sods	128	FS	Monongahela	WV
ome Land	46	FS	Sequoia	CA
agle Cap	10	FS	Wallowa-Whitman	OR
agles Nest	*	FS	Arapaho-Roosevelt	CO
agles Nest	90	FS	White River	CO
llicott Rock	**	FS	Chattahoochee	GA
llicott Rock	139	FS	Nantahala	NC
llicott Rock	140	FS	Sumter	SC
migrant	36	FS	Stanislaus	CA
verglades	187	NPS	—	FL
itzpatrick	79	FS	Shoshone	WY
at Tops	87	FS	Routt	CO
at Tops	88	FS	White River	CO
aliuro	105	FS	Coronado	AZ
ates of the Mountains	70	FS	Helena	MT
earhart Mountain	25	FS	Fremont	OR
ee Creek	132	FS	Cherokee	TN
ila P.A.	162	FS	Gila	NM
ila W.A.	115	FS	Gila	NM
lacier	153	FS	Shoshone	WY
lacier	199	NPS	—	MT
lacier Bay	191	NPS	—	AK
lacier Peak	2	FS	Mt. Baker-Snoqualmie	WA
lacier Peak	3	FS	Wenatchee	WA
oat Rocks	6	FS	Wenatchee	WA
oat Rocks	7	FS	Gifford Pinchot	WA
olden Trout	44	FS	Sequoia	CA
olden Trout	45	FS	Inyo	CA
ospel Hump	61	FS	Nezperce	ID
rand Gulch	250	BLM	—	UT
rand Teton	201	NPS	—	WY
reat Bear	64	FS	Flathead	MT
reat Gulf	305	FS	White Mountain	NH
reat Sand Dunes	173	NPS	—	CO
reat Smoky Mountains	212	NPS	—	TN/NC
reat Swamp	221	FWS	—	NJ
uadalupe Mountains	181	NPS	—	TX
ulf Islands	188	NPS	—	FL

APPENDIX B—(Con.)

Area	Number	Agency	Forest	State
Haleakala	164	NPS	—	HI
Hart Mountain	234	FWS	—	OR
Havasu	235	FWS	—	CA/AZ
Hawaii Volcanoes	165	NPS	—	HI
Hells Canyon	*	FS	Payette	ID
Hells Canyon	11	FS	Wallowa-Whitman	OR
Hells Canyon	12	FS	Nezperce	ID
Hercules-Glades	121	FS	Mark Twain	MO
High Sierra	***	FS	Sequoia	CA
High Sierra	145	FS	Sierra	CA
High Uintas	155	FS	Wasatch	UT
High Uintas	156	FS	Ashley	UT
Hoover	37	FS	Toiyabe	CA
Hoover	38	FS	Inyo	CA
Humbug Spires	243	BLM	—	MT
Hunter Fryingpan	92	FS	White River	CO
Idaho	*	FS	Boise	ID
Idaho	148	FS	Payette	ID
Idaho	149	FS	Challis	ID
Idaho	150	FS	Salmon	ID
Indian Peaks	89	FS	Arapaho-Roosevelt	CO
Isle Royale	184	NPS	—	MN
James River Face	131	FS	Jefferson	VA
Jarbidge	55	FS	Humboldt	NV
J. N. "Ding" Darling	229	FWS	—	FL
John Muir	42	FS	Sierra	CA
John Muir	43	FS	Inyo	CA
Joshua Tree	170	NPS	—	CA
Joyce Kilmer-Slickrock	133	FS	Cherokee	TN
Joyce Kilmer-Slickrock	134	FS	Nantahala	NC
Kaiser	41	FS	Sierra	CA
Kalmiopsis	27	FS	Siskiyou	OR
Katmai	190	NPS	—	AK
Kenai	232	FWS	—	AK
Kenai Lakes	233	FWS	—	AK
Kofa	238	FWS	—	AZ
Lacassine	218	FWS	—	LA
LaGarita	***	FS	Gunnison	CO
LaGarita	94	FS	Rio Grande	CO
Lassen Volcanic	167	NPS	—	CA
Lava Beds	166	NPS	—	CA
Linville Gorge	137	FS	Pisgah	NC
Lone Peak	83	FS	Wasatch	UT
Lone Peak	84	FS	Uinta	UT
Lye Brook	125	FS	Green Mountain	VT
Manzano Mountains	113	FS	Cibola	NM
Marble Mountain	28	FS	Klamath	CA
Maroon Bells-Snowmass	91	FS	White River	CO
Mazatzal	101	FS	Tonto	AZ
Mesa Verde	174	NPS	—	CO
Minarets	39	FS	Sierra	CA
Minarets	40	FS	Inyo	CA
Mingo	216	FWS	—	MO
Mission Mountains	63	FS	Flathead	MT
Missisquoi	240	FWS	—	VT
Mokelumne	34	FS	Eldorado	CA
Mokelumne	35	FS	Stanislaus	CA
Monomoy	220	FWS	—	MA
Mount Adams	8	FS	Gifford Pinchot	PA
Mt. Baldy	104	FS	Apache	AZ
Mt. Hood	14	FS	Mt. Hood	OR
Mt. Jefferson	15	FS	Mt. Hood	OR
Mt. Jefferson	16	FS	Willamette	OR
Mt. Jefferson	17	FS	Deschutes	OR
Mt. McKinley	189	NPS	—	AK
Mt. Rainier	194	NPS	—	WA
Mt. Washington	18	FS	Willamette	OR
Mt. Washington	19	FS	Deschutes	OR
Mt. Zirkel	85	FS	Routt	CO
Mountain Lake	24	FS	Winema	OR
North Absaroka	77	FS	Shoshone	WY
North Cascades Complex	192	NPS	—	WA
Nunivak	231	FWS	—	AK
Okefenokee	225	FWS	—	GA
Olympic	193	NPS	—	WA
Organ Pipe Cactus	176	NPS	—	AZ
Otter Creek	129	FS	Monongahela	WV
Paiute	251	BLM	—	AZ
Paria Canyon	248	BLM	—	UT/AZ
Parker River	241	FWS	—	MA
Pasayten	1	FS	Okanogan	WA
Passage Key	228	FWS	—	FL
Pecos	111	FS	Carson	NM
Pecos	112	FS	Santa Fe	NM
Petrified Forest	175	NPS	—	AZ
Pine Mountain	*	FS	Tonto	AZ
Pine Mountain	100	FS	Prescott	AZ
Pinnacles	169	NPS	—	CA
Point Reyes	168	NPS	—	CA
Popo Agie	154	FS	Shoshone	WY
Powderhorn	247	BLM	—	CO
Presidential Range-Dry River	127	FS	White Mountain	NH
Pusch Ridge	106	FS	Coronado	AZ
Rainbow Lake	118	FS	Chequamegon	WI
Rawah	86	FS	Arapaho-Roosevelt	CO
Red Rock Lakes	214	FWS	—	MT
Rocky Mountain	203	NPS		CO
Saguaro	177	NPS	—	AZ
Salmon River Breaks	146	FS	Nezperce	ID
Salmon River Breaks	147	FS	Bitterroot	ID
Salmon Trinity Alps	143	FS	Klamath	CA
Salmon Trinity Alps	144	FS	Shasta-Trinity	CA
Sandia Mountains	114	FS	Cibola	NM
San Gabriel	50	FS	Angeles	CA
San Gorgonio	52	FS	San Bernardino	CA
San Jacinto	53	FS	San Bernardino	CA

PPENDIX B—(Con.)

ea	Number	Agency	Forest	State
n Juan Islands	213	FWS	—	WA
n Rafael	49	FS	Los Padres	CA
n Pedro Parks	109	FS	Santa Fe	NM
nta Lucia	48	FS	Los Padres	CA
vage Run	82	FS	Medicine Bow	WY
wtooth	*	FS	Boise	ID
wtooth	60	FS	Sawtooth	ID
wtooth	*	FS	Challis	ID
ab Creek	246	BLM	—	WY
apegoat	67	FS	Lolo	MT
apegoat	68	FS	Helena	MT
apegoat	69	FS	Lewis & Clark	MT
lway-Bitterroot	56	FS	Clearwater	ID
lway-Bitterroot	57	FS	Nezperce	ID
lway-Bitterroot	58	FS	Bitterroot	MT/ID
lway-Bitterroot	59	FS	Lolo	MT
quoia-Kings Canyon	197	NPS	—	CA
enandoah	186	NPS	—	VA
ining Rock	138	FS	Pisgah	NC
rra Ancha	102	FS	Tonto	AZ
osey	141	FS	Bankhead	AL
uth Warner	29	FS	Modoc	CA
anish Peaks	151	FS	Gallatin	MT
awberry Mountain	13	FS	Malheur	OR
perstition	103	FS	Tonto	AZ
camore Canyon	97	FS	Kaibab	AZ
camore Canyon	98	FS	Prescott	AZ
camore Canyon	99	FS	Coconino	AZ
ton	80	FS	Bridger-Teton	WY
eodore Roosevelt	182	NPS	—	ND
Thousand Lakes	30	FS	Lassen	CA
Three Sisters	20	FS	Willamette	OR
Three Sisters	21	FS	Deschutes	OR
Uncompahgre	157	FS	Uncompahgre	CO
Upper Buffalo	122	FS	Ozark	AR
Ventana	47	FS	Los Padres	CA
Washakie	78	FS	Shoshone	WY
Welcome Creek	71	FS	Lolo	MT
Weminuche	95	FS	San Juan	CO
Weminuche	96	FS	Rio Grande	CO
Wenaha-Tucannon	9	FS	Umatilla	OR,WA
West Elk	93	FS	Gunnison	CO
Wheeler Peak	108	FS	Carson	NM
Whisker Lake	119	FS	Nicolet	WI
White Mountain	116	FS	Lincoln	NM
Wichita Mountains	217	FWS	—	OK
Wild Rogue	26	FS	Siskiyou	OR
Wilson Mountain	158	FS	Uncompahgre	CO
Wilson Mountain	159	FS	San Juan	CO
Wolf Island	224	FWS	—	GA
Yellowstone	200	NPS	—	WY/ ID/MT
Yolla-Bolly-Middle Eel	32	FS	Shasta-Trinity	CA
Yolla-Bolly-Middle Eel	***	FS	Mendocino	CA
Yosemite	196	NPS	—	CA
Zion	205	NPS	—	UT

* – Area managed by adjacent forest.
** – No significant use, so no data were collected for this forest.
*** – No reply to questionnaire.

INDEX 2. FISH AND WILDLIFE SERVICE REFUGES SURVEYED BUT NOT REPORTED IN DETAIL

Number	Area	State	Acreage
Wilderness			
253	Chamisso	AK	455
254	Clarence Rhode	AK	41,113
255	Tuxedni	AK	5,683
256	Bogoslof	AK	175
257	Simeonof	AK	25,141
258	St. Lazaria	AK	65
259	Hazy Island	AK	32
260	Forrester Island	AK	2,832
261	Washington Islands	WA	179
262	Three Arch Rocks	OR	17
263	Oregon Islands	OR	21
264	Farallon	CA	141
265	U L Bend	MT	20,847
266	Medicine Lake	MT	11,800
267	Bosque del Apache	NM	30,287
268	Bitterlake	NM	9,612
269	Lostwood	ND	5,577
270	Chase Lake	ND	4,228
271	Agassiz	MN	4,000
272	Tamarac	MN	2,180
273	Huron Islands	MI	147
274	Seney	MI	25,150
275	Wisconsin Islands	WI	29
276	Michigan Islands	MI	12
277	West Sister Island	OH	77
278	Fort Niobrara	NB	4,635
279	Big Lake	AR	2,114
280	Moosehorn	ME	7,386
281	Brigantine	NJ	6,681
282	Swanquarter	NC	9,000
283	St. Marks	FL	17,350
284	Lake Woodruff	FL	1,732
285	Pelican Island	FL	6
286	Island Bay	FL	20
287	Florida Keys	FL	6,152
Proposed Wilderness			
288	Unimak	AK	973,000
289	Izembek	AK	301,451
290	Semidi	AK	256,000
291	Hawaiian Islands	HI	1,742
292	Malheur	OR	30,000
293	Imperial	CA	14,470
294	Charles Sheldon Antelope Range	NV	321,400
295	Anaho Island	NV	748
296	Rice Lakes	MN	1,406
297	Mille Lacs	MN	1
298	Valentine	NB	16,317
299	Crescent Lake	NB	24,502
300	White River	AR	975
301	Bombay Hook	DE	2,000
302	Assateague Island	MD	1,740
303	Back Bay	VA	2,165
304	Pea Island	NC	180
305	Mattamuskeet	NC	590
306	Cedar Island	NC	180
307	Santee	SC	163
308	Noxubee	MS	1,200

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Washburne, Randel F.; Cole, David N. Problems and practices in wilderness management: a survey of managers. Res. Pap. INT-304 . Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 56p.

Presents results of a survey of the managers of units within the National Wilderness Preservation System (NWPS) and prospective additions. Summarizes use characteristics, management problems, management techniques, nonconforming uses, and other topics. Provides tabular summary of findings.

KEYWORDS: wilderness, recreation, visitor characteristics, management techniques, carrying capacity, resource impacts, survey research

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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**Intermountain
Forest and Range
Experiment Station
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Research Paper
INT-305

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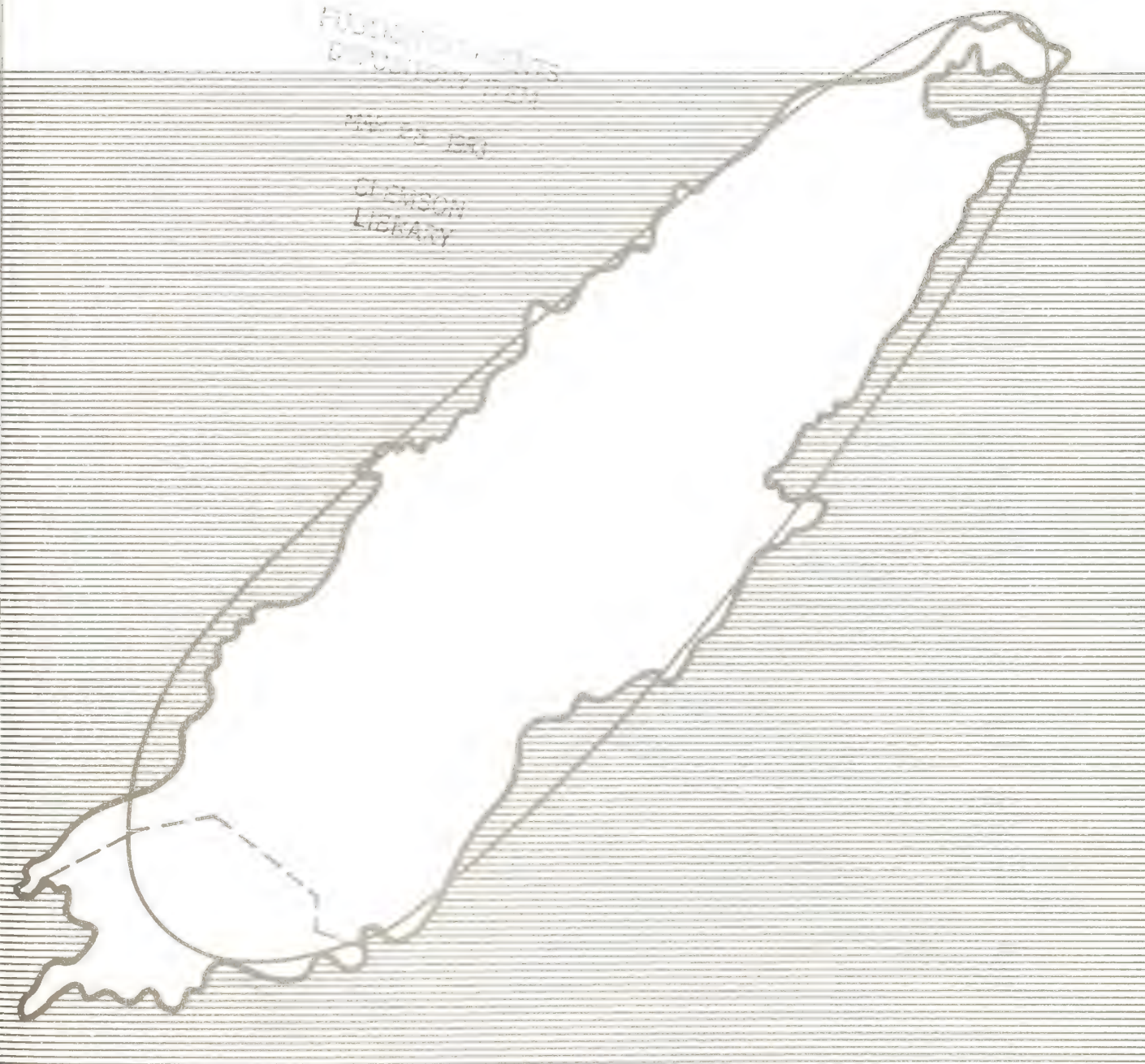
Predicting Wind-Driven Wild Land Fire Size and Shape

Hal E. Anderson



THE AUTHOR

HAL E. ANDERSON has been team leader of the basic research section of the Fire Fundamentals Research Work Unit since 1979. He joined the staff at Intermountain Station's Northern Forest Fire Laboratory in Missoula, Mont., in 1961 and served as project leader of the fire physics project from 1962 to 1966 and of the fuel science project from 1966 to 1979. He previously worked with General Electric Company from 1952 to 1961 on thermal and nuclear instrumentation. He received his B.S. degree in physics from Central Washington University in 1952.

RESEARCH SUMMARY

Fire behavior predictions have become part of the initial fire assessment, both for fire as a treatment or fire as a force to be suppressed. How fast a fire may grow in size and how much fireline there may be are valuable information factors to fire management staff. Critical analysis of wild land fire records and previous wind tunnel research on fire growth provided the basis for a mathematical approach to estimating fire size and shape using a double ellipse model. Equations have been developed to estimate the flank and backing fire spread rates, fire area, perimeter, and length to width ratio, and to plot fire shape.

Graphs and tables present the relationships developed, and five wild land fires show how the estimation matches field situations. In addition, the simple ellipse concept is presented with a quadratic equation solution for determining minor and major axes. These results are compared to the fire size and perimeter tables carried in most fireline notebooks.

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INTRODUCTION

When an unplanned wild land fire occurs, the fire management staff needs to know the expected size and shape so the impact on land resources can be assessed and suppression forces dispatched. Early attempts to satisfy the need included analysis of fire records by Hornby (1936) that provided a table of minimum, probable, and maximum perimeter for various fire sizes. This table is in the Forest Service Handbook, FSH 5109.12, Fireman's Handbook, June 1966, amendment No. 4, Figure 2, page 33.5—3, and has been reemphasized by Cargill (1970) in terms of forward rate of spread and elapsed time. Most Forest Service regions carry some form of this table in their Fireline Handbook supplements.

Rothermel's (1972) mathematical model provides the means for predicting how far a fire would travel in a given situation, but in the early 1970's there was no way to use that information to estimate fire size and shape. However, Fons[1] in 1940 provided data that could be applied to the problem. Fons' work will be referred to throughout this paper. It was possible to develop from Fons' data an approach where only the downwind spread distance and the windspeed at midflame height were needed to estimate the fire's acreage, perimeter, and shape.[2] This approach is used for estimating fire behavior, utilizing computer facilities for calculations, and evaluating fire hazards of slash (Albini 1976a, 1976b; Puckett and others 1979). In addition, the procedure is incorporated into the S-590 Fire Behavior Officer course conducted at the National Advanced Resource Technical Center at Marana, Ariz., and the proposed S-390 Fire Behavior training package (see appendix I).

This paper (1) documents the development and formulation of the procedure, (2) reviews observations and methods of assessment, and (3) provides examples that will aid testing the procedure. Illustrations show how this model can be used to confirm other fire behavior models.

BACKGROUND

Firefighters and researchers generally agree that wild land fires are circular in shape immediately after ignition, but as wind, slope, and other environmental factors influence the fire, its shape becomes elliptical (Hawley and Stickel 1948; Brown and Davis 1973; Peet 1967; Pirsko 1961; McArthur 1966; Curry and Fons 1938; Mitchell 1937). McArthur (1966) states that the stronger the wind the more narrow and elongated the fire burns. He presents a relationship between fire shape and wind velocity, using a straightforward ellipse where the length to width ratio varied from 1.0 to approximately 6.0. This range in length to width ratio primarily reflects the grassland fuels being considered. The most probable ratio selected by Cheney and Bary (1969) is 4:1 for grasslands, while Van Wagner (1969) uses a ratio of 2:1 as an example for a forest fire. This compares with the average fire shape found by Hornby (1936) where the perimeter is about 1.5 times the perimeter of a circle of equal area. An ellipse with a length to width ratio of 5:1 represents that average fire shape. Work by Peet (1967) in the western Australia Jarrah Forest indicated the ratio of 2:1, but he noted the fires became more ovoid in shape as rate of forward spread increased.

Similar observations by Curry and Fons (1938) show the change with a steady wind or a variable direction wind. An additional display of fire shapes presented by Fons (1946) contribute to using two semiellipses to define size and shape. Mitchell (1937) observes that fires become oval or egg-shaped after a few minutes, with the narrow end being in the direction of forward spread. These features of wind-influenced wild land fires become more obvious with the use of infrared imagery for fire

[1]Fons, Wallace L. Forest fuels progress report No. 6, May 20, 1940. California Forest and Range Experiment Station, copy on file at the Pacific Southwest Forest and Range Experiment Station, Forest Fire Laboratory, Riverside, CA.

[2]Anderson, Hal E. Memorandum to R. C. Rothermel and W. C. Fischer, on file at Northern Forest Fire Laboratory, Missoula, MT, August 10, 1973.

mapping and detection (Hirsch and others 1968). The Sundance Fire (Anderson 1968), with documented weather and fire spread history, was mapped by infrared imagery (Hirsch 1968). The long elliptical shape was evident, although some of the narrowness was due to nonlinear features of the scanning portions of the infrared mapping equipment.

Aerial photography points out such characteristics as shown in the examples given by Wade and Ward (1973). The Air Force Bomb Range Fire and the Exotic Dancer Fire show elliptical patterns in the vegetation bands that outline the fire's perimeter at progressive stages of development. Controlled burning in the Everglades has generated the same pattern of burning in sawgrass stands (Klukas 1972). The initial circular, then oval, shape of the fire's perimeter is usually lost in the subsequent burnout of the area.

McArthur (1966) showed that the length to width ratio is a function of windspeed, so only an estimate of the forward spread rate is needed to calculate fire size. Van Wagner (1969) used an ellipse to estimate fire size and perimeter. Although it is a simple and flexible mathematical method, it is necessary to know or estimate three rates of spread at the head, flanks, and rear of the fire. A similar but expanded approach is provided by Simard and Young (1978) who define the spread rate at the head, two flanks, and the rear of the fire. This approach provides a means to evaluate aerial and ground suppression options against fire growth. A fire potential assessment model developed by Van Gelder (1976) determines the length to width ratio by slope, windspeed, and fuel characteristics. Fire size is estimated by use of available fire weather reports and a fuel model to apply Rothermel's (1972) fire spread model. Examples show that the elliptical model is useful for rapid evaluation of the fire potential of given situations. Earlier application of the concept presented by Storey (1972) uses input parameters of size at discovery, the length to width ratio, and the forward rate of spread. An expansion by Bratten (1978) considers the size at attack and size at containment. Length to width ratios and forward spread rates were used as defining parameters. Other work on the containment problem by Albini and others (1978)—involving a complex analysis incorporating forward, flank, and backing rates of spread—show that the general shape follows an elliptical profile.

Experimental Results of 1939

Fons reported on a series of 198 test fires conducted in a low velocity wind tunnel. The objective was to establish the effect of compactness in pine litter on the spread of surface fires with varying wind velocity and moisture content (table 1). Wind velocity that was measured 1 ft (0.3 m) above the fuel surface was varied from 2 to 12 mi/h (3.2 to 19.3 km/h). This measurement is comparable to midflame height. Fires were started from a point source and allowed to grow until they were approximately 18 inches (45.7 cm) in width. At that point, wind generation was stopped and the fire was quenched with water to preserve the fire's shape (fig. 1).

The notation used in the development of the mathematical description of fire size and shape is in figure 1. The focus, f_1, represents—the origin of the fire and the point from which all measurements to the perimeter were made by Fons. The forward distance traveled with a given rate of spread for a given interval of time is defined by d. The other dimensions are defined as:

Table 1.—Forward spread of firs in ponderosa pine needles under various conditions (from Fons[1])

Wind velocity	Fuel moisture content	Fuel bed compactness (inches)					
		0.06	0.08	0.10	0.12	0.14	0.
Miles per hour	*Percent*	*Forward spread - feet per minute*					
0	4	0.38	0.54	0.67	0.76	0.84	0.
0	8	0.30	0.42	0.49	0.55	0.60	0.
0	12	0.19	0.27	0.32	0.36	0.38	0.
0	16	0.10	0.15	0.18	0.18	0.19	0.
2.0	4	0.93	1.32	1.62	1.78	1.85	2.
2.0	8	0.72	0.98	1.17	1.28	1.30	1.
2.0	12	0.51	0.68	0.82	0.89	0.90	1.
2.0	16	0.30	0.42	0.45	0.51	0.45	0.
4.0	4	1.80	2.53	3.12	3.34	3.50	3.
4.0	8	1.40	1.93	2.29	2.42	2.53	2.
4.0	12	1.02	1.39	1.62	1.70	1.80	2.
4.0	16	0.60	0.85	1.00	1.03	1.03	1.
6.0	4	2.89	4.09	4.98	5.38	5.75	6.
6.0	8	2.26	3.18	3.74	4.01	4.20	4.
6.0	12	1.68	2.30	2.68	2.85	3.00	3.
6.0	16	1.00	1.45	1.72	1.78	1.80	2.
8.0	4	4.16	6.02	7.40	8.10	8.70	10.
8.0	8	3.34	4.74	5.56	6.15	6.60	7.
8.0	12	2.50	3.45	4.09	4.37	4.63	5.
8.0	16	1.58	2.25	2.66	2.83	2.95	3.
10.0	4	5.69	8.40	10.52	11.75	12.90	15.3
10.0	8	4.70	6.68	8.00	8.97	9.70	10.7
10.0	12	3.57	4.95	5.95	6.46	6.83	7.7
10.0	16	2.34	3.32	4.00	4.24	4.58	5.2
12.0	4	7.59	11.32	14.40	16.70	18.70	21.6
12.0	8	6.36	9.13	11.16	12.52	13.40	14.9
12.0	12	4.93	6.88	8.30	9.15	9.60	10.8
12.0	16	3.40	4.84	5.84	6.36	6.70	7.6

[1]See footnote 1 in text.

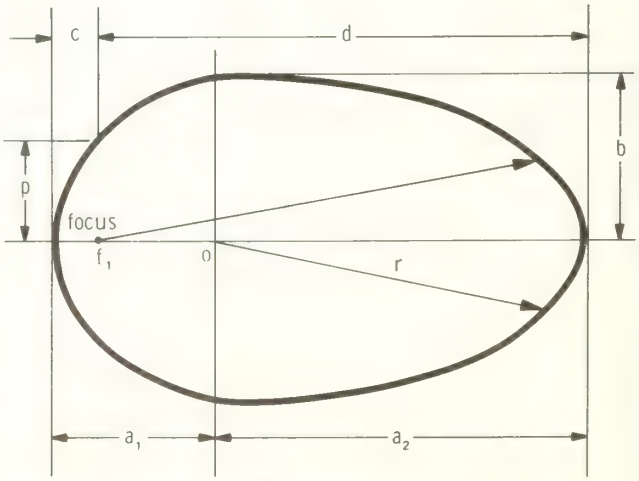


Figure 1.—Definitions of dimensions used for a two semiellipse model of fire shape.

a_1 = major axis of semiellipse at the rear of the fire,
a_2 = major axis of semiellipse at the front of the fire,
b = the common minor axis, the maximum flanking fire spread distance,
c = the portion of axis, a_1, that is the backing fire spread distance,
p = semilatus rectum of the rear semiellipse and represents the flanking fire at the origin.

Fons made measurements of the downwind distance from the origin to the perimeter at various angles from the direction of maximum spread (table 2). He used data from the experiments to generate a series of cross plots involving windspeed, compactness, and moisture content. With these cross plots, differences between the observed data and the fitted data provided residuals that were used for obtaining the final set of curves. Table 1 shows the values of forward spread from the final curves and table 2 presents the statistical measures Fons computed for forward spread at each windspeed.

Table 2.—Statistical measures of ratios of forward spread to spread at other angular distances[1]

Cases	Wind velocity	Direction from maximum spread[2] 10°	20°	30°	40°	60°	90°	130°	180°
Number	*Miles per hour*								
		Mean spread ratio (actual)							
32	2.2	0.943	0.843	0.739	0.649	0.525	0.431	0.362	0.328
34	4.3	.882	.724	.600	.510	.399	.312	.246	.218
40	6.4	.815	.607	.468	.377	.276	.205	.157	.142
35	8.4	.753	.522	.391	.311	.223	.163	.119	.105
33	10.5	.689	.443	.314	.243	.169	.115	.079	.066
24	12.5	.664	.413	.293	.226	.154	.103	.066	.057
		Standard deviation of spread ratio							
32	2.2	0.025	0.041	0.050	0.060	0.054	0.049	0.073	0.084
34	4.3	.040	.063	.073	.073	.069	.063	.058	.057
40	6.4	.045	.062	.062	.056	.045	.034	.035	.043
35	8.4	.041	.052	.049	.043	.033	.028	.030	.032
33	10.5	.041	.046	.039	.033	.027	.021	.023	.025
24	12.5	.054	.053	.044	.037	.028	.021	.020	.020
		Standard deviation of spread ratio - percent							
32	2.2	2.7	4.9	6.8	9.2	10.3	11.4	20.2	25.6
34	4.3	4.5	8.7	12.2	14.3	17.3	20.2	23.6	26.1
40	6.4	5.5	10.2	13.2	14.9	16.3	16.6	22.3	30.3
35	8.4	5.4	10.0	12.5	13.8	14.8	17.2	25.2	30.5
33	10.5	6.0	10.4	12.4	13.6	16.0	18.3	29.1	37.9
24	12.5	8.1	12.8	15.0	16.4	18.2	20.4	30.3	35.1

[1]See footnote 1 in text.
[2]Directions expressed as angular distances in degrees from direction of maximum spread

Fons assumed that the shape of the burned area in any one fuel type is independent of compactness and moisture content. He confirmed this by comparing the means of the ratio of angular spread distance to maximum spread distance obtained within each wind class for the upper and lower ranges of compactness and moisture content (see examples in table 3). The analysis found that the shape of the burned area was dependent only upon the wind velocity. The ratio of maximum length to width for mat beds of ponderosa pine needles was found to be a function of wind velocity by:

$$\frac{(d + c)}{b} = 1.0 + 0.50\,U \qquad (1)$$

where:
c + d = total spread distance, according to figure 1,
b = minor axis, according to figure 1,
U = wind velocity in miles per hour, at midflame height.

For field tests in ponderosa pine needles, the constant was found to be 0.44 rather than 0.50.

Table 3.—Samples of Fons'[1] data illustrating that compactness and moisture content do not influence fire shape

Moisture content	Compactness	Wind-speed	Fractional spread in different directions from origin 10°	20°	30°	40°	60°	90°
Percent	*Inches*	*Mi/h*	*Ratio of angular distance to distance of maximum spread*					
6.8	0.067	2.2	1.00	0.83	0.75	0.58	0.50	0.42
6.9	.160		.93	.87	.73	.67	.53	.47
11.9	.067		1.00	.80	.80	.80	.60	.40
11.6	.160	2.2	1.00	.90	.80	.70	.60	.50
5.3	.067	6.4	.90	71	52	43	.33	.29
4.8	.160		81	.61	.49	.40	28	19
11.2	.067		.84	63	.47	.42	31	.26
12.1	.160	6.4	.87	65	52	39	.32	26
4.7	.067	12.5	.76	.53	.39	.30	.21	.14
6.2	.140		.64	.33	.22	.16	.10	.06
11.1	.067		.64	.39	.27	.21	.14	.11
13.7	.160	12.5	.62	.42	.30	.24	.16	.11

[1]See footnote 1 in text

Development of Fire Shape Model

Analysis of the above data show that the elliptical shape describes results closely. The best fit of the experimental data was found to be with two semiellipses.

The original development[3] considered the spread distance at various angles as fractions of the forward spread distance, d, as presented in Fons' data tables 1 and 2. The dimensions of the double ellipse were analyzed as functions of windspeed using data in Fons' tables and from the curves of fire shape at various windspeeds (fig. 2). Relationships between dimensions of an ellipse besides log regressions were used to express each dimension as a function of windspeed. The minor semiaxis, b, was defined in terms of p and a_1 using the semilatus rectum expression for an ellipse. Further study showed that b could be better described as a log function of windspeed. The dimensions of Fons' curves were reevaluated as fractions of the spread distance, d (table 4).

A least-square fit of log regressions for the following dimensions provided equations as functions of windspeed and fractions of the forward spread distance:

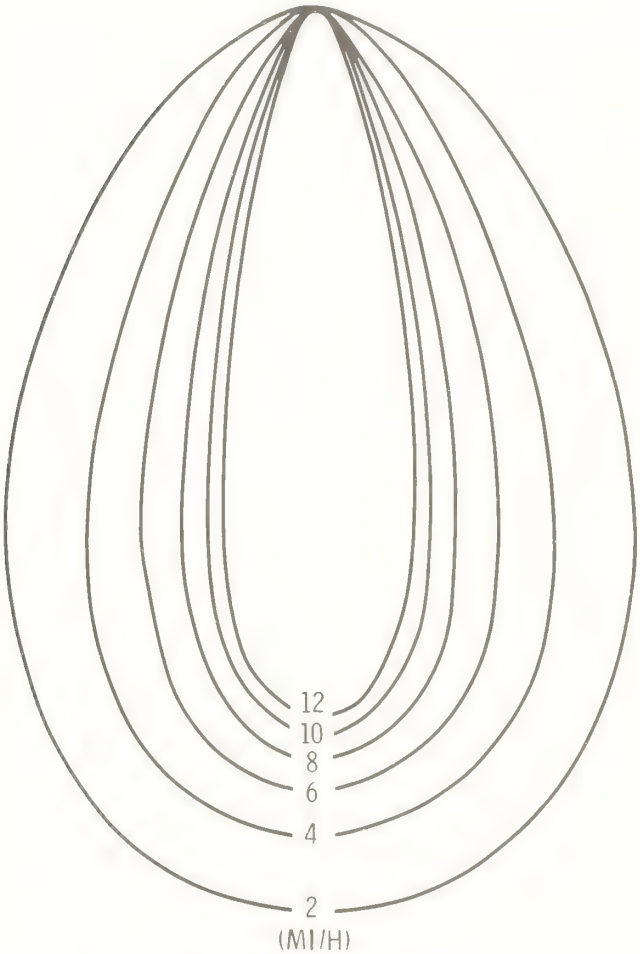


Figure 2.—Diagrams showing influence of wind velocity on shape of burns.

[3]See footnote 2, page 1

Table 4.—Summary of data measured from Fons'— curves (fig. 2) for fire shape and used for equations 2, 3, 4, and 6

Windspeed	a_1 fraction	b fraction	c fraction	frac
Mi/h				
0		0.500	0.500	0.5
2	0.560	.465	.348	.4
4	.416	.348	.230	.3
6	.346	.260	.160	.2
8	.358	.210	.112	.1
10	.346	.163	.072	.1
12	.315	.140	.058	.0

[1]See footnote 1 in text.

$$c = 0.492 \text{ EXP } [-0.1845 \text{ U}], \quad r^2 = 0.996$$
$$S\hat{y} \cdot x = 0.162$$

$$p = 0.542 \text{ EXP } [-0.1483 \text{ U}], \quad r^2 = 0.993$$
$$S\hat{y} \cdot x = 0.140$$

$$a_1 = 2.502\,[88\text{U}]^{-0.30}, \quad r^2 = 0.918$$
$$S\hat{y} \cdot x = 0.046$$

$$a_2 = 1 + c - a_1$$

$$b = 0.534 \text{ EXP } [-0.1147 \text{ U}], \quad r^2 = 0.988$$
$$S\hat{y} \cdot x = 0.143$$

These equations provide a means of quantifying important dimensions of the double ellipse representation of fire shape. When these values along with the spread distance are used in equations for area and perimeter, we can estimate fire growth. In addition, the length to width ratio and the envelope of the burn area can be estimated.

Calculations of area and perimeter require multiplying the fractional expressions of ellipse dimensions by the forward spread distance. The following equations have been used or adapted to make estimates of the fire dimensions (Albini 197 1976b; Albini and Chase 1980):

$$\text{Area} = A = \frac{\pi b d^2}{2}(a_1 + a_2); \text{ ft}^2, \text{ m}^2, \text{ etc.}$$

$$\text{Perimeter} = P = \frac{\pi k_1 d}{2}(a_1 + b) + \frac{\pi k_2 d}{2}(a_2 + b); \text{ ft,}$$

$$k_n = 1 + \frac{M_n^2}{4} + \frac{M_n^4}{64} + \frac{M_n^6}{256} \cdots$$

(Bauneister

$$M_n = (a_n - b)/(a_n + b)$$

(Bauneister

Equation 9 can be simplified for ease of computation with a less than 1 percent loss in accuracy by eliminating the terms after M_n^2:

$$k_n = 1 + \frac{M_n^2}{4} \qquad (9)$$

For graphic presentation of the fire shape, the perimeter is plotted by using the intercept of the major and minor axes, 0, as the origin. This is possible because the minor axis is common to both semiellipses and both semimajor axes can be defined in terms of d, the forward distance traveled along the major axis, and U, the windspeed. Any point on the perimeter is defined by:

If $\cos \emptyset \geq 0$, a positive value:

$x = (a_2 \cos\theta)d$

$y = (b \sin\theta)d$

If $\cos \theta < 0$, a negative value:

$x = (a_1 \cos\theta)d$

$y = (b \sin\theta)d$

where θ = angular degrees from the forward direction with 0 as the origin. The origin of the fire is defined as $c - a_1$, the focus of the semiellipse containing the backing fire.

With these equations and conditional statements, it is possible to predict the area burned by a fire and the distance around its perimeter. Windspeed and the forward rate of spread are the only inputs needed.

ANALYSIS RELATED TO FIRE SIZE AND SHAPE

Just how well these mathematical models match Fons' graphic data (fig. 2) was analyzed by comparing measured fire data with calculated values. The fire shapes of figure 2 were scaled at 1 inch = 1,000 ft (8.3 cm = 1 km). As size and shape dimensions were calculated, a plot of the fire shape was generated so computations could be compared to results obtained from figure 2 and the plotted shapes. The plotted shapes were prepared for windspeeds of 2, 6, and 12 mi/h (3.2, 9.6, and 19.3 km/h). The values computed and those measured were found to be within ±2 percent of each other. Fons' fire shapes of figure 2 and the model generated plots were within ±9 percent of each other for area measurements and within ±3 percent for perimeter measurements. The area and perimeter measurements were made with a compensating polar planimeter for area and a map measurer for the perimeter. The measured and computed values are presented in table 5 and shown in figures 3 and 4.

Perimeter may be underestimated because of the natural variability that exists in the field. A few of the variables contributing to an irregular and longer fire edge are windspeed and direction, slope and topography, and changes in fuel distribution.

The greatest benefit of using these equations is that only two input variables—wind at midflame height and rate of spread (distance for a given time)—are needed to compute area, perimeter, backing fire distance, flanking fire distance, their ratios to the heading fire, and the maximum length to width ratio. These estimates have proven valuable to various elements of fire management, but it must be remembered that the original data were taken on fires burning through pine needle beds without variation in wind direction. Outputs such as the length to width ratio may show that fuel size (surface area to volume ratio) and fuel bed packing ratio (fuel volume per unit volume) have an influence.

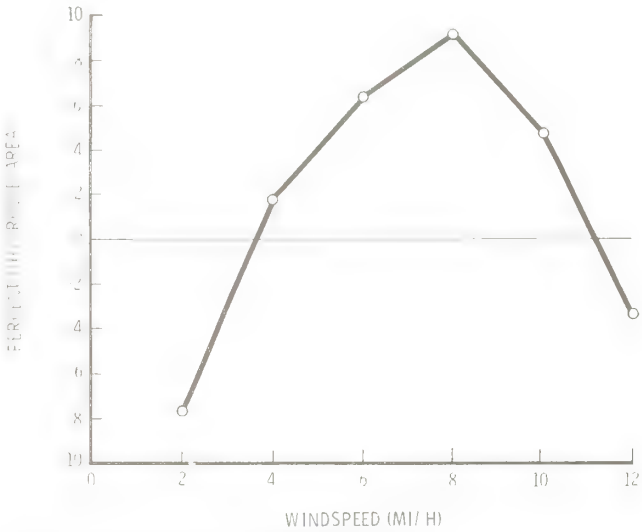


Figure 3.—Deviations of mathematical model versions from Fons' diagrams for fire size and shape, area.

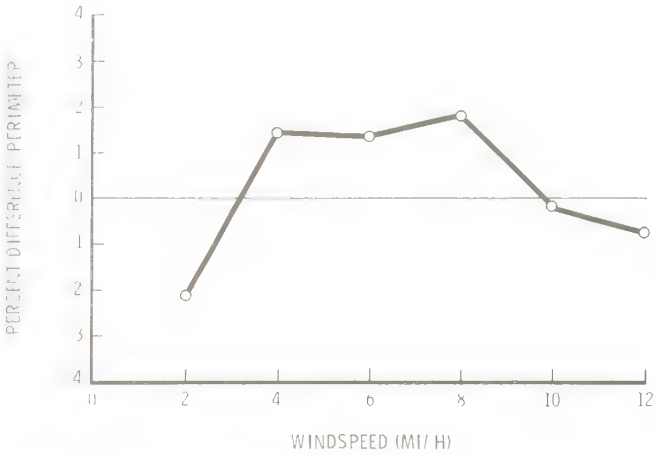


Figure 4.—Deviations of mathematical model versions from Fons' diagrams for fire shape, perimeter.

Table 5.—Comparison of Fons[1] diagrams with fire size and shape mathematical model outputs using a forward spread distance of 5,000 ft

Version	Windspeed Mi/h	Graphic acres	Computed acres	Graphic miles	Computed miles
Fons	2	556.4		3.38	
Model		512.8	513.5	3.28	3.31
Fons	4	369.5		2.88	
Model			376.0		2.92
Fons	6	265.1		2.59	
Model		281.5	282.0	2.60	2.63
Fons	8	196.0		2.37	
Model			214.0		2.42
Fons	10	157.5		2.27	
Model			165.0		2.26
Fons	12	132.4		2.17	
Model		127.9	128.0	2.12	2.15

[1]See footnote 1 in text

Comparison of Fire Size Properties

Hornby (1936), using 146 fire records and 102 hypothetical fires, showed that for a constant area reference, the most probable perimeter was 1.5 times that of a circle with equal enclosed area. In addition, he found that 92 percent of the fire shapes investigated would have perimeters less than 2 times that of a circle of equal area. These are equivalent to length to width ratios of 5:1 and 9.7:1, respectively. Mitchell (1937) related the head fire rate of spread to the rate of perimeter increase using the relationship for circles of the perimeter to the diameter. He suggested the simplest approach was to multiply the head fire rate of spread by 3 for an estimate of the rate of perimeter increase. Hanson's (1941) analysis of 140 fires in the Forest Service's Region 4 relates the length of line in chains to the final acreage of the fire. Brown's (1941) analysis of 65 class "C" fires in Region 2 produced a graph of minimum, average, and maximum control line lengths in chains for fires up to 1,000 acres (404.7 ha) at control. He found that π times the long axis of the fire agreed closely to the perimeter. For fires under 20 acres (8.1 ha) he found the most probable perimeter to be 1.67 times the perimeter of a circle of equal area.

Length to width ratios did not appear to receive much attention until McArthur published his Australian research on grassland fires (1966). He recognized that the elliptical shape provides a good approximation of fire shape. With the statement on his "grassland fire danger meter" that perimeter increase can be taken as 2.5 times the forward spread, fire sizes can be analyzed in terms of perimeter, area, and length to width ratio. Assuming an elliptical shape, we have a unique solution for any fire where two of these dimensions are known.

Using the concept of equal area shapes as Hornby (1936) introduced, we can establish the minimum perimeter an elliptical fire can have unless control action has truncated the fire shape. Working with the simple ellipse we need to use the equations for area and perimeter:

$$\text{Area} = \pi ab = A, \text{ units}^2 \tag{11}$$

$$\text{Perimeter} = (a + b)\, k\pi = P, \text{ units} \tag{12}$$

where:

a = semimajor axis,
b = semiminor axis,
k = equation (9).

By using the area equation (11) to define b we can substitute into equation (12) and reduce it to a quadratic equation:

$$\pi k a^2 - aP + kA = 0$$

The two axes, a and b, can be calculated from:

$$a = P + \frac{\sqrt{P^2 - 4\pi k^2 A}}{2\pi k}$$

and

$$b = P - \frac{\sqrt{P^2 - 4\pi k^2 A}}{2\pi k}$$

and by successive approximations determine the unique combination of area, perimeter, k, and length to width ratio that a given set of conditions.

Using this technique, a series of areas and perimeters were evaluated and length to width ratios, ℓ/w, were determined (fig. 5). Note that area will be the square of the unit of measure used for perimeter—ft^2 for area when perimeter is in feet, for example. Perimeter may be any unit of length that is suitable.

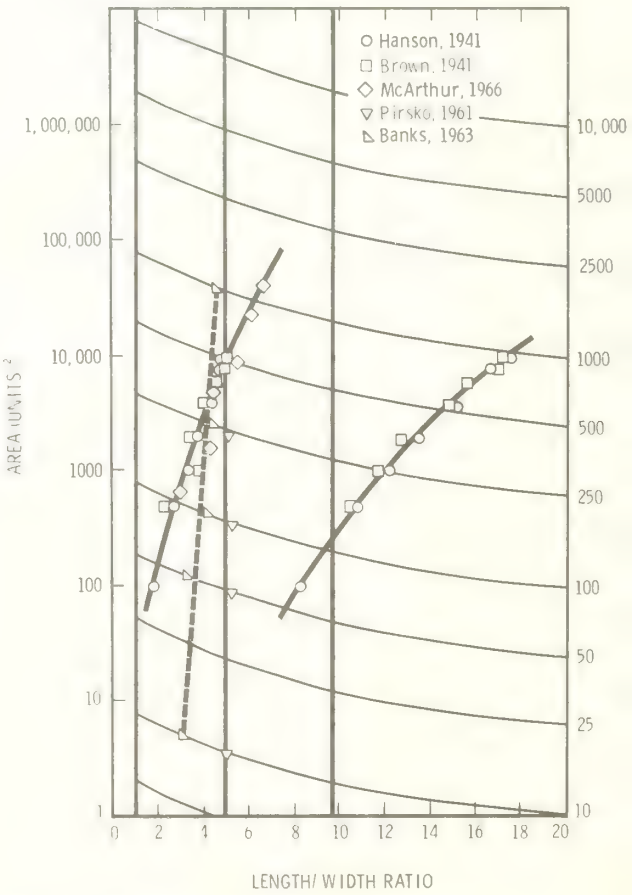


Figure 5.—The relationship of area, perimeter, length to width ratio for elliptical-shaped fires and comparison of several appraisals of fire size and shape relationships.

Hornby (1936) expresses fire size and shape in terms of the length of perimeter for an ellipse to the circumference of a circle of equal area. For the no-wind, no-slope condition, the circle and the ellipse are equal in perimeter and the ℓ/w ratio is 1:1. He expressed the most probable fire size as when the perimeter of the ellipse is 1.5 times the circumference of a circle of equal area and the ℓ/w ratio is 5:1. The fires Hornby analyzed showed that 92 percent of all the perimeters investigated were less than 2.0 times the circumference of a circle with equal area—or having a ℓ/w ratio of 9.7:1. These three descriptions of fire size and shape are identified in figure 5 by the vertical lines at:

1. Minimum perimeter = circumference = 1:1 ℓ/w ratio,
2. Most probable perimeters 1.5 circumference = 5:1 ℓ/w ratio,
3. Maximum perimeter = 2.0 circumference = 9.7:1 ℓ/w ratio.

Figure 5 presents the data previously cited by Hanson (1941), Brown (1941), McArthur (1966), Pirsko (1961), and Banks (1963), and shows how the other interpretations compare to Hornby's.

Brown (1941) and Hanson (1941) both used an analysis method of fire size and shape that used the standard error to define the expected minimum and maximum values of perimeter for a given fire size. McArthur's (1966) values for area and perimeter, when wind is a factor, agree with the most probable values found by Brown and Hanson. These results for most probable and maximum values are shown in figure 5 as the solid lines through the data points for ℓ/w ratios from 2:1 to 7:1 and 8:1 to 17:1. These data points can be expressed mathematically in empirically determined equations:

For ℓ/w ratios < 7

$$A = 4.74\,(\ell/w)^{4.638}, \text{ area.}$$

For ℓ/w ratios > 7

$$A = 1.62 \times 10^{-4}\,(\ell/w)^{6.285}, \text{ area.}$$

This suggests that a greater range of combinations for area, perimeter, and ℓ/w ratio occurs than the procedure used by Hornby (1936) can accommodate. This is a result of constraining the perimeters to 1.5 and 2 times the circumference of a circle with equal area. The ℓ/w ratios are then fixed at 5 and 9.7 as representing the most probable and the expected maximum ℓ/w ratio respectively.

The relationship of the length to width ratio to the average wind on the flame can be expressed with the equations developed from Fons' wind tunnel data. Using the dimensions of figure 1 where d equals 1 for normalizing, we can describe the ratio of total fire length to maximum fire width:

$$\ell/w = (1 + c)/2b \qquad (16)$$

Since the backing and flanking dimensions are expressed as fractions of the forward rate of spread distance, the forward distance has a value of unity. Combining equations 2 and 6 as indicated above and clearing the fractional form, we can express the length to width ratio (fig. 6) by:

$$\ell/w = 0.936\,\mathrm{EXP}(0.1147U) + 0.461\,\mathrm{EXP}(-0.0692U) \qquad (17)$$

where U = windspeed at 1.5 ft or midflame miles per hour.

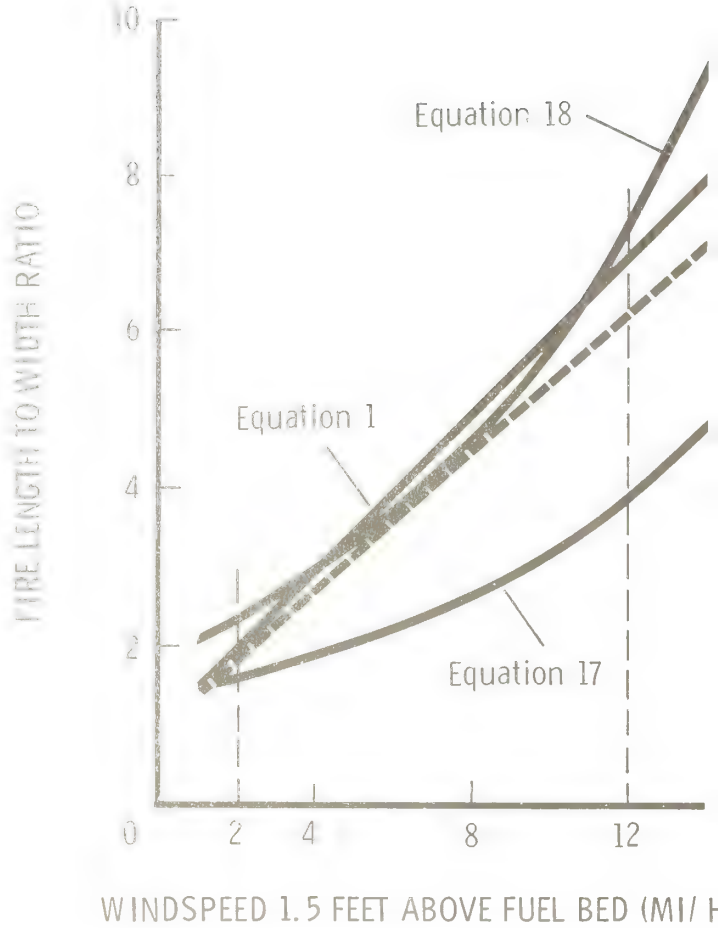


Figure 6.—Relation of the length to width ratio and windspeed 1.5 ft (45.7 cm) above the fuel bed. The dotted lines at 2 and 12 mi/h (3.2 and 19.3 km/h) show the range of experimental data used by Fons.[1]

Fons found a relationship of length to width to wind that is linear in nature over the range of winds examined:

$$\frac{d + c}{2b} \quad 1.0 + 0.5\,U \qquad (1)$$

where U is miles per hour. The solid line in figure 6 represents this equation, and the dashed line presents a similar equation with a coefficient of 0.44 for fires burning in ponderosa pine needle litter beds in the forest.

These equations have nearly twice the slope of equation 16 or 17, primarily because only the downwind distance and the distance to one side of the centerline of the fire shape are used. Equation 16 can be reduced to a similar form by disregarding the backing distance, c, and using the minor axis dimension, b, as the width:

$$d/b = 1/b = 1/0.534\mathrm{EXP}[\quad 0.1147U] \qquad (18)$$
$$\text{or } 1.873\,\mathrm{EXP}[0.1147U]$$

This curve matches the line from equation 1 from 2 to 12 mi/h (3.2 to 19.3 km/h) windspeeds.

Because it is generally difficult to identify the fire starting point and establish the centerline of the fire shape, it is recommended that the total fire length and width be considered for field applications. This also conforms to the general use of the simple ellipse as is currently being done. However, it must be remembered that the distance, d, is from the focus opposite the head of the fire and not the major axis of a simple ellipse (see fig. 1).

The application of the results of this analysis must consider the average wind on the flame. This may require calculating that value from wind measurements made at some other height. The variability of the wind along with the array of fuels and topography that a fire may encounter are probably the most significant factors in establishing a fire's size and shape. How well the double ellipse or simple ellipse matches field observations will depend on how wisely an observer selects a windspeed and a fuel bed description so reasonable inputs are made to the mathematical models.

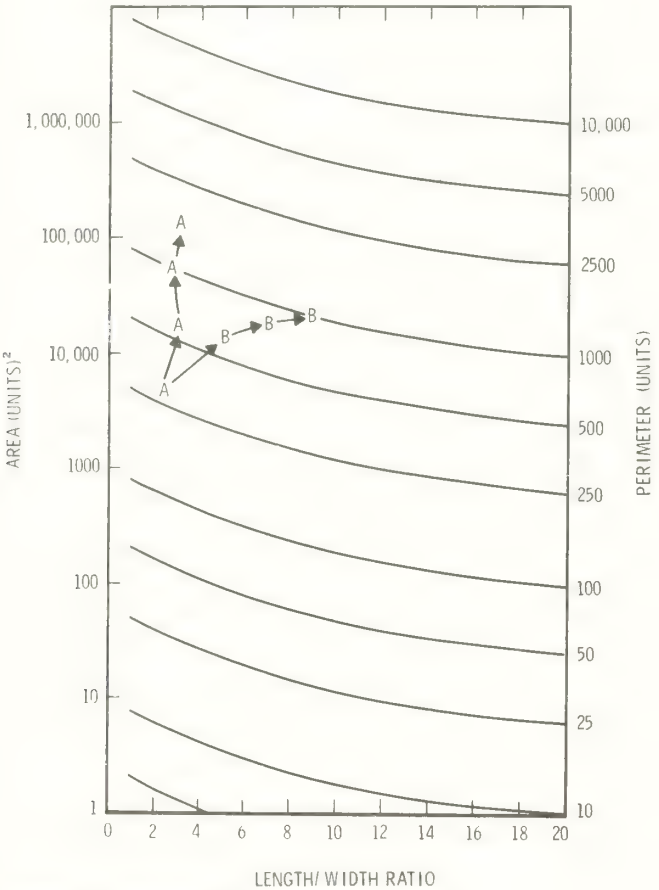


Figure 7.—Wisconsin's Fire Suppression Handbook examples of fire size and shape with and without good control action.

Initial tests of the model and the assumptions used have been made with historical data and are tabulated in appendix II. These are checks for the reasonableness of the model and provide indications of how wind, fuels, and topography must be considered as validation opportunities become available. The documented values from field observations in appendix II are compared to computed values from the double-ellipse mathematical model and the quadratic equation approach to the single ellipse model.

Interpretation of the combinations of fire size and shape parameters must be given careful consideration if historic fires are to be used as data for developing aids to fire management. An example is the Wisconsin Fire Suppression Handbook,[4] which contains examples of fires with no control and good control. In figure 7 the data from appendix II of this report are plotted to show the differences. Fire "A" was not controlled and shows that for given weather and fuel conditions the ℓ/w ratio remains constant while the area and perimeter continue to increase. Fire "B" shows the results of good flanking fire control and pinching off attack on the fire front. The area and perimeter are increasing at a decreasing rate while the ℓ/w ratio increases rapidly. When utilizing historic fires it must be recognized that either good fire control or a sudden increase in windspeed or a change in wind direction can change ℓ/w ratios.

Comparison to Field Observations of Wildfires

The following five fires had enough documentation to show how fire shape and size relationships change with time. The time histories of fire shape and size, graphically presented in figure 8, show that Hornby's (1936) approach is reasonable. Time since fire start is in the direction the arrows point. When the wind is stable and fuels are constant, the fires tend to orient vertically in figure 8.

Close agreement can be achieved between the field observations and the mathematical computation when the wind profile is considered. Albini and Baughman (1979) present a procedure that is used to depict the average wind on the flame by reducing the windspeed at 20 ft (6 m) above the vegetation cover to what would be present at the location of the flame front. Winds may be reduced to the value at the vegetation upper surface or to a point within the cover depending on whether a crown fire or a surface fire occurred.

Following are brief summaries of each example. These comparisons are valid only to the extent that effective suppression action or major fuel changes have not taken place, restricting fire growth.

[4]Excerpts provided by Jim Miller, Fire Staff Specialist, Rhinelander, Wis.

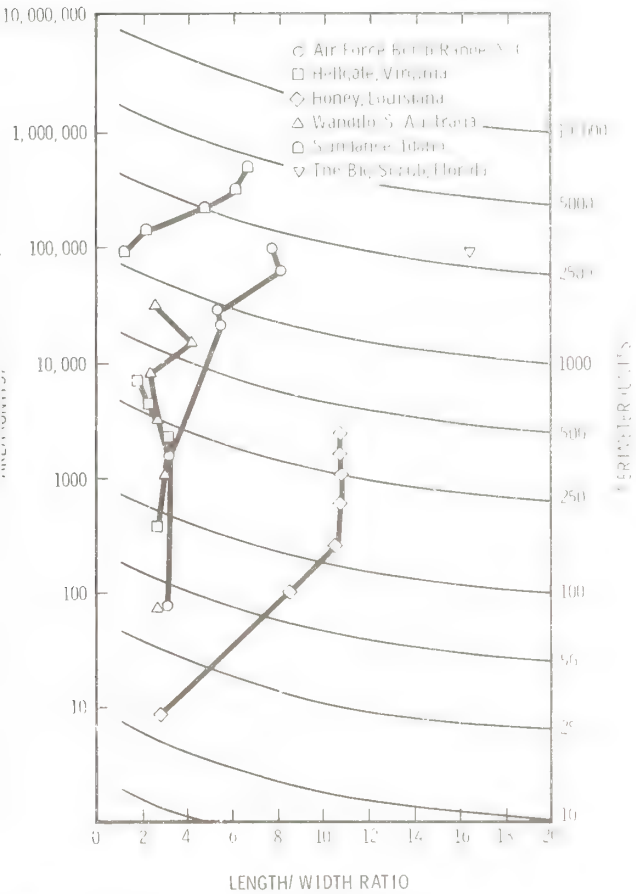


Figure 8.—Fire size and shape changes during the history of observed fires.

Example Fires with the Critical Values Tabulated

Example 1:

Air Force Bomb Range Fire on March 22, 1971 (Wade and Ward 1973) started at 1028 and began crowning about 1230. This continued until 1745, after which the fire encountered wet fuel and wind changes occurred with fronts moving through the area. Wind direction changes complicate use of the ellipse model and make results more uncertain. Notice that the wind acting on the flame to match observations was to reduce the 20 ft (6.1 m) wind to 9.4 mi/h (15.0 km/h) for the fire burning in grass and low shrubs. After 1230 the observed wind was only reduced to 15 mi/h (24.0 km) because the fire was carried in the crown of the pond pine (*Pinus serotina* Michx.) plantation. The fit of the adjusted double ellipse is shown in figure 9.

Example 1. The Air Force Bomb Range Fire in Florida started in brush and grassy fuels and about 2 hours later started crowning in pine plantations (*P. serotina*). Fire start was 1028 on March 22, 1971

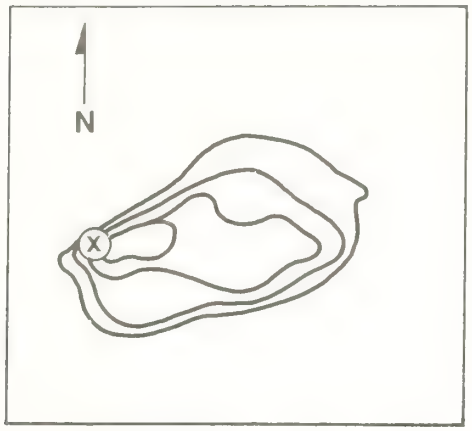
Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1100.0 hours			
Area	8.0 acres	8	5.6	8
Perimeter	5 miles	.5	5	5
Distance	2 miles	2	2	2
Windspeed	W 20.0 mi/h		12.2	9.4
l/w	3:1	3.2:1	4:1	3:1
Time	1226			
Area	155	155	102	159
Perimeter	2.1	2.1	2.0	2.2
Distance	9	9	9	9
Windspeed	WSW 20		13.0	9.5
l/w	3.1:1	2.8:1	4.3:1	3:1
Time	1439			
Area	2,094	2,094	2,845	2,099
Perimeter	10.2	10.2	10.3	9.9
Distance	4.6	4.6	4.9	4.6
Windspeed	SW 15		12.5	15.0
l/w	5.4:1	5.8:1	3.5:1	5.4:1
Time	1537			
Area	2,975	2,975	4,589	2,982
Perimeter	11.6	11.6	12.3	11.5
Distance	5.3	5.6	5.3	5.3
Windspeed	SW 15		10.9	14.4
l/w	5.3:1	5.2:1	3.5:1	5.1:1
Time	1636			
Area	6,518	6,518	6,297	6,485
Perimeter	20.5	20.5	20.8	20.9
Distance	10.1	10.1	10.1	10.1
Windspeed	SSW 20		19.0	18.8
l/w	8.1:1	7.8:1	8.4:1	8.2:1
Time	1745			
Area	9,796	9,796	12,434	9,819
Perimeter	29.1	29.1	25.6	25.1
Distance	12.1	14.4	12.1	12.1
Windspeed	SW 20		16.3	18.3
l/w	7.8:1	10.7:1	6.2:1	7.8:1

Figure 9.—Air Force Bomb Range Fire, March 26, 1971, in North Carolina; changes in size and shape.

Example 2:
The Hellgate Fire of April 18, 1965, as reported by Taylor and Williams (1967), burned in forest cover of pine and oak with heavy litter and slash. Rapid spread with crowning and spotting occurred from 1350 to 1500. Maximum rate of spread was from 1400 to 1430 at 110 chains/h to the east. Wind shifts started to occur after 1430. The wind reduction was 0.332 for the double ellipse ℓ/w ratio to match field observations. These suggest the fire growth was controlled by the surface fire even though there was crowning and spotting. The wind reduction factor of 0.332 for 1430, 1500, and 1600 matches Albini and Baughman's (1979) values for open-stocked, intolerant young to mature species, 40 to 100 ft (12.2 to 30.5 m) tall. The fit of the double ellipse shape is shown in figure 10.

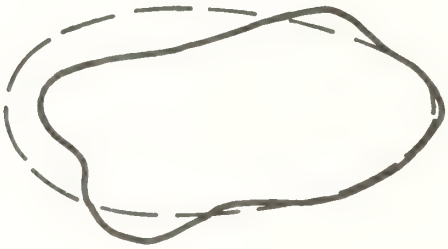
Example 2. The Hellgate Fire in Virginia was detected at 1335 on April 18, 1965, in an area with heavy litter and slash on the surface. The heavy surface fuels contributed to the fire quickly crowning out in the pine and oak overstory.

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1400.0 hours			
Area	40.0 acres	40	39.5	40
Perimeter	1.0 mile	1	1	1.0
Distance	.4 mile	.4	.4	4
Windspeed	SW 15-20.0 mi/h		6.6	7.7
ℓ/w	2.5:1	2.2:1	2.3:1	2.5:1
Time	1430.0			
Area	243.0	243	235	243
Perimeter	2.8	2.8	2.7	2.7
Distance	1.1	1.3	1.1	1.1
Windspeed	SW 30-50.0		10.0	9.5
ℓ/w	3:1	3.3:1	3.2:1	3:1
Time	1500			
Area	485	485	481	485
Perimeter	3.3	3.3	3.4	[illegible]
Distance	1.2	1.3	1.2	1.2
Windspeed	SW 15-20.0		[illegible]	5.5
ℓ/w	2.1:1	1.8:1	2.1:1	2.1:1
Time	1600			
Area	756	756	700	756
Perimeter	4.0	4.0	4.1	4.1
Distance	1.4	1.4	1.4	1.3
Windspeed	SW 15		5.0	3.6
ℓ/w	1.8:1	1.6:1	2:1	1.8:1



Fire size and shape at 1400 hours, 4/18/65.
Fan shape suggests some wind variability.
Measured fire size is 40 acres.

Fire size and shape at 1430 hours, 4/18/65.
Measured fire size is 243 acres.



Fire size and shape at 1500 hours.
Measured fire size is 485 acres.
Fastest spread rates have occurred.

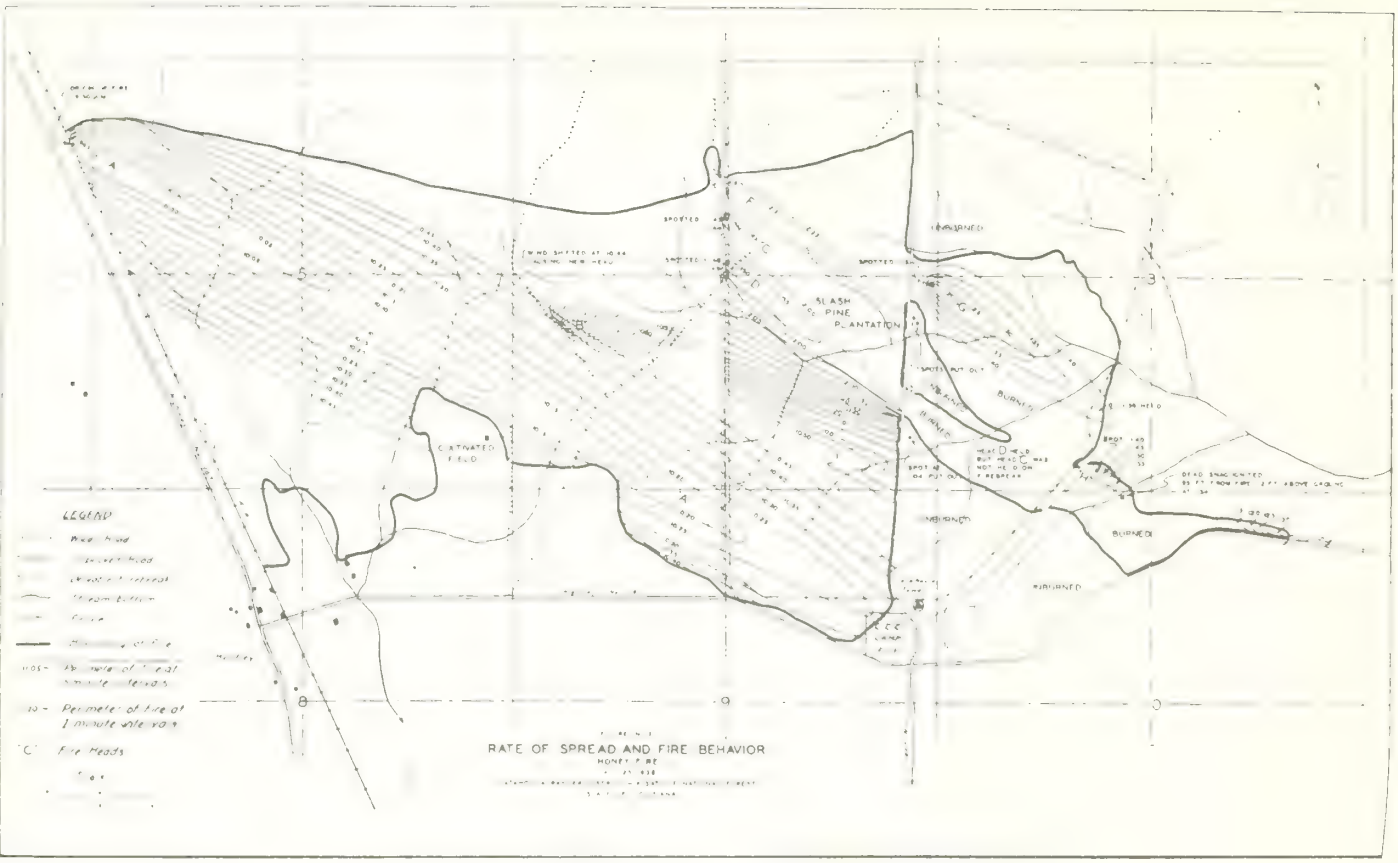
Fire size and shape at 1600 hours.
Measured fire size is 756 acres.

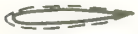
Figure 10.—The Hellgate Fire exhibited high spread rates with crowning and spotting. Passage of weather fronts after 1600 hours caused spread in several directions, eliminating further use of the fire shape model, April 18, 1965. Dotted fire shapes are computer estimates and solid lines are observations.

Example 3:
The Honey Fire of January 25, 1938, was documented by Olsen (1941) with detailed plotting of the perimeter during the first hour. The fire burned predominantly in broomsedge (*Andropogan* sp.) and other grasses to provide a uniform, extremely dense fuel bed. Wind measurements were made at 3.5 ft (1.1 m) above the ground and indicated a maximum wind of 9.9 mi/h (15.8 km/h). However, the ℓ/w ratios for the period of 1005 to 1025 indicate windspeeds on the fire of 19 to 20 mi/h (30.4 to 32.0 km/h) were present. The difference could be due to variability in the wind or may be due to the fuels having a larger surface area to volume ratio than the ponderosa pine needles fuel bed used by Fons. The fire shapes in figure 11 were closely matched by the double ellipse equations. Note in figure 7 that the fire accelerated during the first 10 minutes, and then stabilized at a nearly constant ℓ/w ratio. Spot fires later in the burn period show similar fire shapes. Spot fire "F" that burned just after 1230 had a ℓ/w ratio at 1233 of 6.1:1, which from figure 6, or equation 17, corresponds to an average wind on the fire of about 16 mi/h (25.6 km/h). This is within 2 mi/h (3.2 km/h) of the maximum wind between 1220 and 1233 hours. An hour later spot fire "G" developed a shape with a ℓ/w ratio of 3.5:1, which indicates a wind decrease to about 11 mi/h (17.6 km/h). The narrative indicates these spot fires in the eastern portion of the burned area were in blackjack oak (*Quercus marilandica*) stand with less fire-carrying fuel. The fire was contained in this area at 1443 hours.

Example 3. The Honey Fire of Louisiana burned through broomsedge (*Andropogon* sp.) and other grasses on January 25, 1983.

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	0955 hours			
Area	.9 acres	.9	1.4	.9
Perimeter	.2 miles	.2	2	2
Distance	.1 miles	.1	1	1
Windspeed	6.7 mi/h		6.7	8.4
ℓ/w	2.7:1	3.4:1	2.3:1	2.7:1
Time	1000			
Area	10.2	10.2	31.3	10.2
Perimeter	.9	.9	1.0	.8
Distance	.4	.4	.4	.4
Windspeed	9.9		9.9	19
ℓ/w	8.4:1	9.3:1	3.1:1	8.4:1
Time	1005			
Area	27	27	96	27
Perimeter	1.5	1.5	1.7	1.5
Distance	.7	.8	.7	.7
Windspeed	9.9		9.9	21
ℓ/w	10.5:1	10.5:1	3.1:1	10.5:1
Time	1010			
Area	60.5	60.5	254	60.5
Perimeter	2.4	2.4	2.8	2.3
Distance	1.2	1.2	1.2	1.1
Windspeed	9.9		9.9	21.1
ℓ/w	10.6:1	12.4:1	3.1:1	10.6:1
Time	1015			
Area	109	109	462	109
Perimeter	3.3	3.3	3.8	3.1
Distance	1.6	1.6	1.6	1.5
Windspeed	9.9		9.9	21.2
ℓ/w	10.7:1	12.4:1	3.1:1	10.7:1
Time	1020.0			
Area	167.0	167	640	167
Perimeter	3.9	3.9	4.4	3.6
Distance	1.9	1.9	1.9	1.8
Windspeed	9.9		9.9	20.3
ℓ/w	9.7:1	11.3:1	3.1:1	9.7:1
Time	1025			
Area	250.8	250.8	911.6	250.8
Perimeter	4.6	4.6	5.3	4.4
Distance	2.2	2.3	2.2	2.2
Windspeed	9.9		9.9	20.2
ℓ/w	9.6:1	10.5:1	3.1:1	9.6:1





Fire size and shape ten minutes, 1000 hrs., after fire start.
Size is just over 10 acres and ℓ/w ratio is above 8:1.

Fire size and shape twenty minutes, 1010 hrs., after fire start.
Size is just over 60 acres and ℓ/w ratio over 10:1.

Fire size and shape thirty minutes, 1020 hrs., after fire start.
Size is just over 167 acres and ℓ/w ratio is under 10:1.

Fire size and shape thirty-five minutes, 1025 hrs., after fire start.
Size is just over 250 acres and the ℓ/w ratio is under 10:1.

—— **ACTUAL FIRELINE**
— — **MODEL OUTPUT**

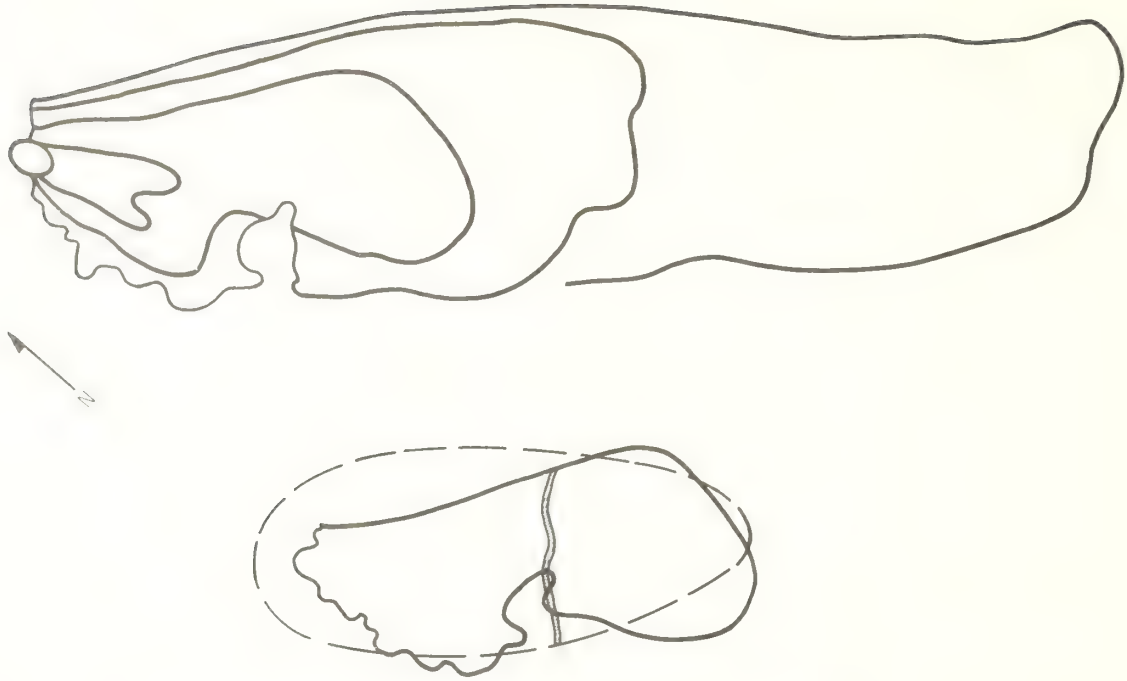
Figure 11.—The Honey Fire, taken from "An analysis of the Honey Fire" by C. F. Olsen, Fire Control Notes, vol. 5, No. 4, October 1941.

xample 4:

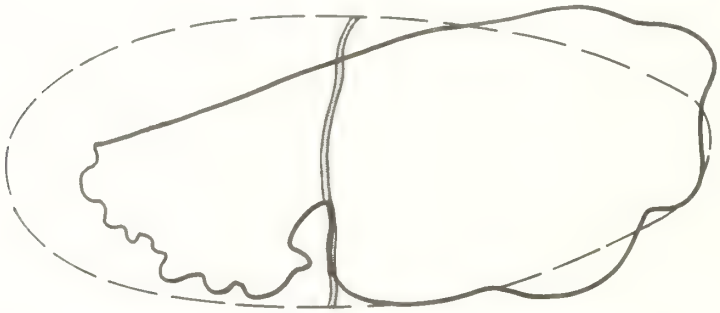
he Wandilo Fire of April 5, 1958, in South Australia near Mt. ambier was documented by McArthur and others (1966). A fire storm" developed and caused the death of eight refighters. The fire started in tea tree (*Leptospermum* spp.) rub as a surface fire with no crowning, but entered an un-inned, unpruned cluster pine (*Pinus pinaster*) plantation about 230 and started crowning and spotting. The wind reduction as from about 20 mi/h (32.0 km/h) at 33 ft (10 m) to 6 mi/h (12.2 km/h). This reduction suggests the fire was pre-ominantly a scrub fire, which is indicated in the narrative. The re moved into a Monterey pine (*Pinus radiata*) stand and pro-eeded at a somewhat slower rate with occasional crowning. The re area and perimeter at this time suggest a slower growth rate with winds on the fire of 6 to 7 mi/h (9.6 to 11.2 km/h). The wind at 33 ft (10 m) was averaging 22 mi/h (35.2 km/h) so the reduction factor was 0.31. The general area of the fire storm contained stands of die-back timber and heavier fuel accumulation that facilitated crowning. This allowed crown fires to develop, and downwind spotting caused almost an area ignition. It is difficult to say whether the fire advanced by spotting or crowning, but the fire shape by the double ellipse model fits reasonably well with a wind on the fire of about 12.5 mi/h (20.0 km/h). The reduction factor for 23 mi/h (36.8 km/h) to 12.5 mi/h (20.0 km/h) is 0.54, which agrees with what would be expected just above a vegetation layer as compared to the wind 33 ft (10 m) above the layer. The elliptical fire shapes for 1330, 1500, and 1530 hours are presented in figure 12.

Example 4. The Wandilo Fire of April 5, 1958, in South Australia started in tea tree scrub as a surface fire, but after entering unthinned, unpruned pine plantations it became a crown fire.

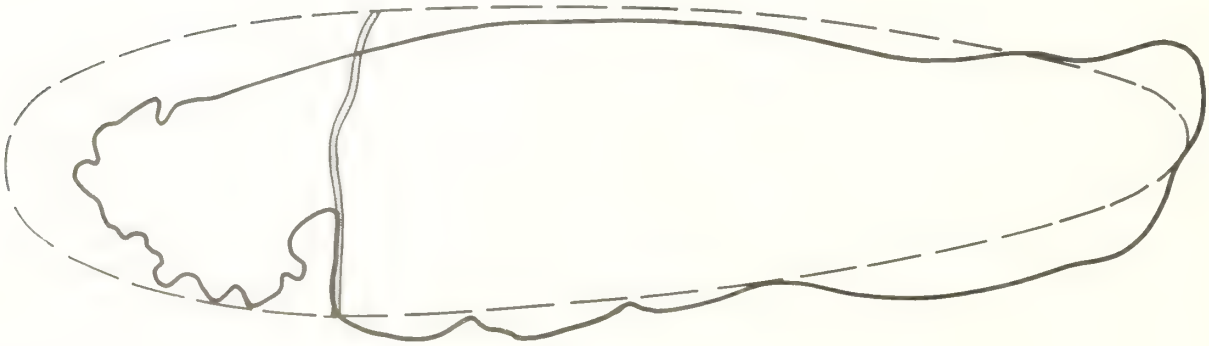
Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1140 hours			
Area	8.0 acres	8	13.5	8
Perimeter	.3 miles	.3	.5	.5
Distance	.2 miles	.1	.1	.2
Windspeed	NNW 17.0 mi/h		1.0	7.75
ℓ/w	2.6:1	1.3:1	1.5:1	2.6:1
Time	1230			
Area	114	114	144	114
Perimeter	2.2	2.2	2.3	1.8
Distance	1.0	1.0	1.0	.7
Windspeed	NWN 20		12.3	8.8
ℓ/w	2.8:1	5:1	4:1	2.8:1
Time	1330			
Area	381.	381	381	381
Perimeter	3.9	3.9	4.0	3.2
Distance	1.5	1.8	1.8	1.2
Windspeed	NW 17-22		13.8	7.6
ℓ/w	2.5:1	4.4:1	4.7:1	2.5:1
Time	1500			
Area	900	900	986	900
Perimeter	5.9	5.9	6.2	4.8
Distance	2.0	2.8	2.8	1.8
Windspeed	NW 21-23		12.8	6.8
ℓ/w	2.3:1	4.2:1	4.2:1	2.3:1
Time	1530			
Area	1,547	1,547	3,016	1,547
Perimeter	8.4	8.4	9.7	7.6
Distance	3.4	4.0	4.0	3.4
Windspeed	NW 23		10	12.4
ℓ/w	4.1:1	5.3:1	3.2:1	4.1:1
Time	2230.0			
Area	3,383.0	3,383	3,383	—
Perimeter	14.5	14.5	9.5	—
Distance	4.6	7.1	3.7	—
Windspeed	14.0		7.7	—
ℓ/w	2.5:1	7.5:1	2.5:1	—



Fire size and shape at 1330 hours with over 380 acres burned and a l/w ratio of 2.5 :1.



Fire size and shape at 1500 hours with 900 acres burned and a l/w ratio of 2.3 :1.



Fire size and shape at 1530 hours with 1547 acres burned and a l/w ratio of 4.1 :1.

Figure 12.—The Wandilo Fire in South Australia on April 5, 1958, produced severe spotting that phased properly with the winds to initiate a "fire-storm" shortly after 1500 hours.

Example 5:
The Sundance Fire of September 2, 1967, was reported by Anderson (1968) and illustrates a wind-driven fire moving from a fire line 3 to 4 mi (6.4 to 9.6 km) wide. The fire size and shape were examined at 1500, 1700, 1900, 2100, and after 2300 hours (fig. 13). The fire shapes do not fit well because the fire on this day began its spread from a line rather than a point. Spotting began some time near 1500 hours and continued through at least 2000 hours. Crowning started after 1500 and played a significant role after 1800 hours. Midflame winds on the fire front began exceeding 12 mi/h (19.3 km/h) at about 1800 hours and appear to have been near 16 to 17 mi/h (27.4 km/h) until after 2300 hours. Up through 1700 hours the fire was generally a surface and shrub fire and the wind reduction coefficient was 0.18, indicating overstory material was slowing the wind's movement. After 1700 the wind reduction was less because the fire spread was more through the shrub and tree crown material. The earlier fire advance to the west is not included.

Even though the double ellipse model doesn't match a line fire during its intermediate growth stages, a projection of the final size and shape after an extended run appears possible. Figure 13 shows this in the projection of the size after 2300 on September 1, 1967. The average wind on the flame used to estimate a total run, must consider the windspeed variation over time. It also must consider how the free-stream windspeed above the vegetation surface is reduced as the location of the flame front is reached. In this case the average windspeed was 11.5 mi/h (18.5 km/h). For fires with wide fire fronts, it is probably better to represent each edge of the fire as a point source, project the fire advance from these points, and inscribe the combined area.

Other considerations that can be made with the material developed on fire size and shape include estimation of the backing and flanking rates of spread, interpreting the change in size and shape over time, and using the quadratic equation to determine any one of the three properties defining size and shape knowing the other two.

In appendix II, the Freeman Lake Fire in Idaho illustrates a fast moving crown fire that covered 20,000 acres (8 094 ha) in 12.5 hours (example 8). Jemison (1932) reports that by the morning of August 4, 1931, the fire had covered an area 5 mi wide and 11.5 mi long (8.0 km by 18.5 km), with some spot fires 15 mi (24.1 km) from the origin. Use of the double ellipse model and the wind reduction concepts suggests this fire had a ℓ/w ratio of 2.3:1 for an average wind on the fire of 6.8 mi/h (10.9 km/h). The wind measured at the 150-ft (45.7-m) level at Priest River Experiment Forest was an average of 14.9 mi/h (23.8 km/h), so the wind reduction factor was 0.46, which is reasonable for the upper surface of the vegetation layer or tree crowns. Solving the quadratic equation for perimeter yielded a value of 1,800 chains (27.3 mi or 43.7 km), which agreed with the double ellipse solution for an area of 20,000 acres (8 094 ha). Fires with similar rapid spread and growth have occurred in various regions of the United States. Jim Miller[5] notes that several fires in Wisconsin had the same features—the Brockway and Five Mile Tower Fires of 1977 and the Oak Lake Fire of 1980. The Mack Lake Fire in Michigan[6] has features of fire behavior that are like those of the above fires. Records of these types of fires will help evaluate the model of fire shape, (examples 6 and 7).

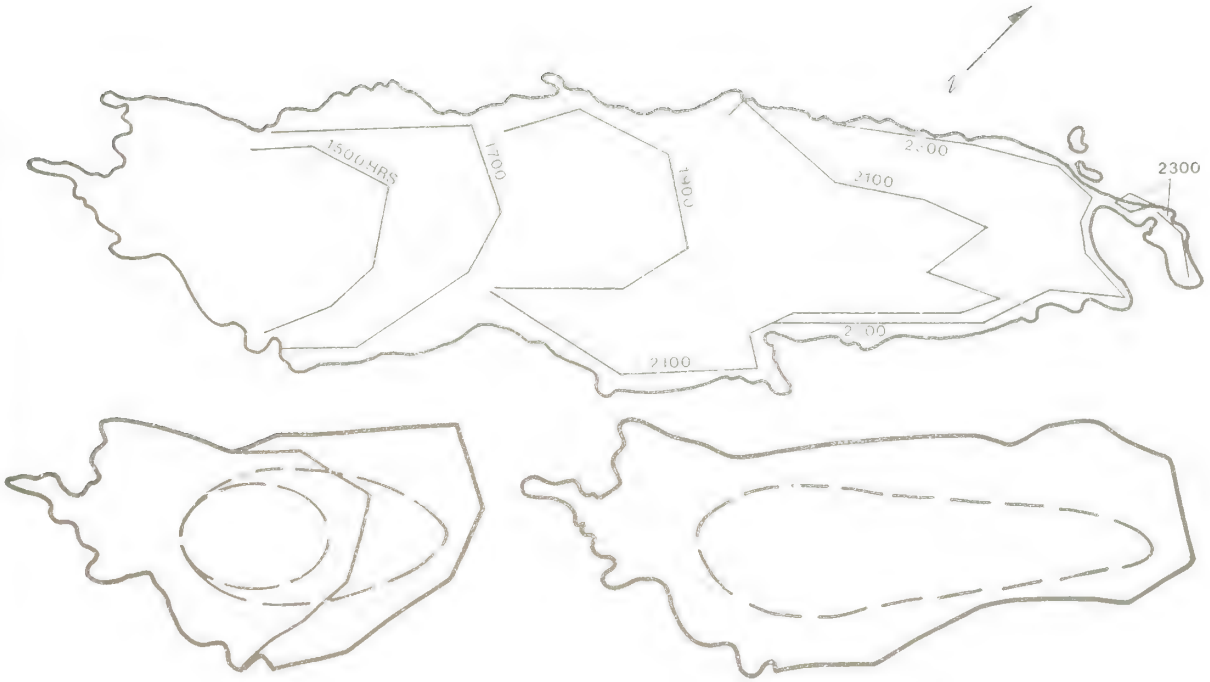
The Big Scrub Fire of 1935 on the Ocala National Forest in Florida— provides a data point at the high ℓ/w ratios shown in figure 7. This fire traveled 18 mi (29.0 km) in 3 hours and had an estimated area of 10,000 acres (4 048 ha). A wind shift resulted in another 25,000 acres (10 120 ha) burning before rains put it out. Winds were reported to be 60 mi/h (96.5 km/h) from the southeast, but the ℓ/w ratio computed from the quadratic equation, if the perimeter is estimated at 2 times the spread distance, was found to be 16:1. This corresponds to an average wind on the fire of 25 mi/h (40.2 km/h). The fire was reported as a crown fire in sand pine, *P. clausa*. The calculated wind reduction factor of 0.42 indicates the average wind was exerted at some point near the upper surfaces of the tree canopy, according to Albini and Baughman's (1979) presentation on estimating windspeed, Big Scrub Fire is given in example 9, Appendix II.

Interestingly, the windspeed of 25 mi/h (40.2 km/h) is essentially the windspeed McArthur (1966) found associated with the maximum rate of spread in grassland fuels. The above windspeed at the 33-ft (10-m) height above the vegetation was found to be associated with fire shapes having ℓ/w ratios of 6:1. If the grass is 1 ft (0.3 m) deep and the flame height is 1 to 1.5 ft (0.3 to 0.5 m) above the upper surface of the grass, the average wind on the flame is computed to be between 15 and 17 mi/h (24.1 and 27.4 km/h). This ℓ/w ratio and windspeed match closely equation 17 results (fig. 6).

[5] Jim Miller, personal correspondence of October 26, 1981, on file at Northern Forest Fire Laboratory.
[6] "The Mack Lake Fire," by Al Simard and others, in preparation.
[7] From notes by Ocala National Forest Ranger John W. Cooper.

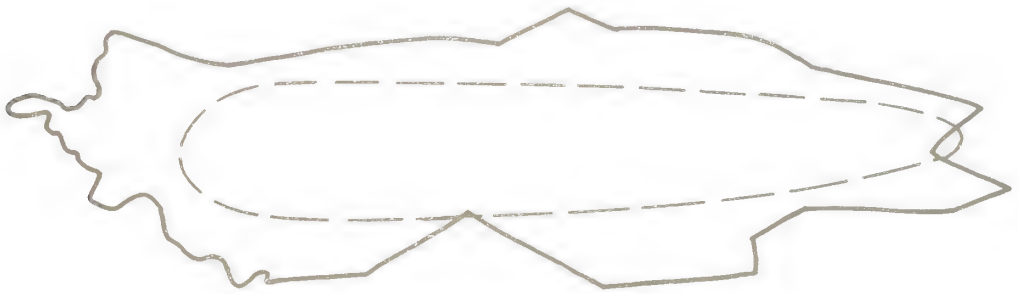
Example 5. The Sundance Fire of September 1, 1967, in Idaho had burned over 6,000 acres before starting its major run on this date. The fire burned through slash and understory shrub material initially. It became a running crown fire in the late afternoon and continued until nearly midnight.

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1300.0 hours			
Area	6,202.0 acres	6,202	—	—
Perimeter	16.2 miles	16..2	—	—
Distance	— miles	7.7	—	—
Windspeed	SW 20.0 mi/h	—	—	—
ℓ/w	1:3.1	4.8:1	—	—
Time	1500			
Area	9,496	9,496	10,564	1,510
Perimeter	18.4	18.4	19.5	5.8
Distance	1.9	8.6	8.6	1.9
Windspeed	SW 24	—	11.9	4
ℓ/w	1.8:1	3.9:1	3.9:1	1.8:1
Time	1700			
Area	15,052	15,052	16,903	5,589
Perimeter	22.7	22.7	24.1	11.5
Distance	4	10.5	10.5	4
Windspeed	SW 29		11.4	5.2
ℓ/w	2.0:1	3.7:1	3.7:1	2.0:1
Time	1900			
Area	22,145	22,145	24,118	6,627
Perimeter	29.6	29.6	31.0	16.5
Distance	7.5	14.0	14.0	7.5
Windspeed	SW 37	—	13.2	13.6
ℓ/w	4.6:1	4.4:1	4.4:1	4.6:1
Time	2100			
Area	35,039	35,039	36,848	15,191
Perimeter	42.7	42.7	43.9	28.0
Distance	13.2	20.7	20.7	13.2
Windspeed	SW 45	—	16.2	16.1
ℓ/w	6.1:1	6.2:1	6.2:1	6.1:1
Time	After 2300			
Area	53,227	53,227	55,025	22,581
Perimeter	54.9	54.9	56.1	35.5
Distance	16.8	26.8	26.8	16.9
Windspeed	SW 49-52		17.1	16.9
ℓ/w	6.6:1	6.8:1	6.8:1	6.6:1

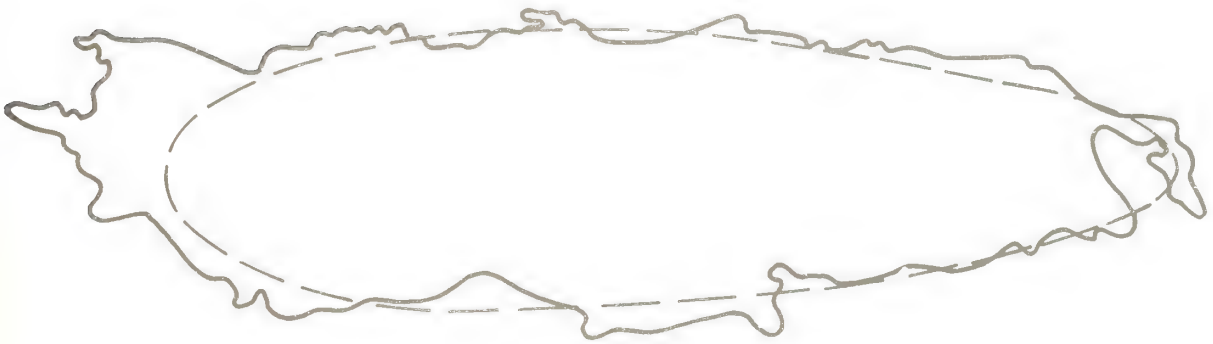


Fire size and shape at 1500 hours, just under 9500 acres. At 1700 hours, just over 15,000 acres.

Fire size and shape at 1900 hours, approximately 22,145 acres.



Fire size and shape at 2100 hours with area of over 35,000 acres.



Fire size and shape after 2300 hours with area near 53,000 acres.

Figure 13.—The Sundance Fire of September 1, 1967, started its run on a wide front such that projection from a single point appears too narrow. However, using the total spread distance and an average wind speed of 11.5 mi/h (18.5 km/h), shows a good fit to fire size after 2300 hours.

CONCLUSIONS

The double ellipse formulation developed from Fons' wind tunnel data is providing useful estimates of fire size, shape, and other physical dimensions for field use. The development allows the fire size and shape to be estimated from the downwind distance traveled in a specified time and the average wind influencing the fire. Equations are provided that can express the backing and flanking fire rates of spread so fires that have grown from a spot fire to the line fire or to an irregular-shaped area fire can be projected. This allows the opportunity for projecting fire growth from existing fire lines.

The accuracy of the equations for area and perimeter is within 10 percent of the area and perimeter determined graphically for Fons' fire sizes and shapes. The greatest uncertainty is in selecting the windspeed and the forward rate of spread. Since upper winds and terrain effects must be considered along with the vegetative cover to assess wind, estimates of windspeed will have considerable uncertainty about them. In addition, wind is an input to predicting the rate of spread of a fire. However, the use of historical fire data may help determine the resolution that is possible for field situations. If we assume that the model is accurate, working backward from fire size and spread distances, the average winds on the fire can be estimated. Then fuel models and fire spread mathematical equations can be exercised to provide comparisons to field data. This way confirmation of developed models can be accomplished and correlations developed to allow updating assumptions made in the formulations of equations. Thus, fire size and shape equations may be useful research tools as well as operational aids.

Other uses have been evaluated, including use of the model with historical fire, fuel, and weather records to establish the rate of spread and wind necessary to have produced what is documented. This allows an examination of the wind reduction model (Albini and Baughman 1979) by establishing the wind at midflame height and an estimate of the free-stream winds 20 ft (6.1 m) or more above the vegetation cover. These values can be compared to predicted or observed National Weather Service windspeeds and winds measured at the fire.

The rate of spread necessary to produce the size and shape of the fire can be tested against fire spread models and the various fuel models to determine if any of the fuel models produce predicted values similar to those measured. If none of the fuel models provides a rate of spread as fast as the observed/recorded field documentation, the threshold where spotting is contributing to fire growth can be established. If one or more fuel models equal or exceed the observed rate of spread, fuel model representativeness should be examined.

Either a double ellipse or a simple ellipse fire shape can be used with the equations, and little difference in fire size (acres), perimeter, or fire shape is apparent. However, the most realistic representation seems to be the double ellipse. With either model there will be an error if a backing fire is not possible. The model assumes there is a backing portion to the fire and would overestimate the area and perimeter.

Historical fire data and maps are being assembled to more thoroughly analyze the double ellipse fire shape model; these will be reported later. Weather and fuel data will be acquired so other models can also be tested. Crowning situations can be defined by the wind reduction coefficient needed to match the observed behavior. Investigations on these will complement other work that is addressing the problem of modeling crown fires.

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APPENDIX I.

Tabulation of Area and Perimeter Estimates with the Ellipse Model Prepared by Williams and Duft for the S-390 Fire Behavior Training Package

Area Estimations for Point Source Fires:

Spread distance chains	Effective windspeed, mi/h 1	3	5	7	9	11	13	15	17	19
					Acres					
1	1	.1	1	00	00	00	00	00	00	00
2	.5	3	3	.3	.2	.1	.1	.1	1	00
3	1.1	8	6	.4	3	3	.2	2	.1	.1
4	1.9	1.4	1	.8	6	.5	.4	.3	2	.2
5	2	2	1.6	1.2	9	.7	6	.5	.4	.3
6	4	3	2	1.7	1.3	1.1	8	.7	.5	.4
7	5	4	3	2	1.8	1.4	1.1	9	7	.6
8	7	5	4	3	2	1.9	1.5	1.2	.9	.7
9	9	6	5	3	3	2	1.9	1.5	1.2	9
10	11	8	6	4	3	2	2	1.8	1.5	1.2
11	14	10	7	5	4	3	2	2	1.8	1.4
12	17	12	9	6	5	4	3	2	2	1.7
13	20	14	10	8	6	4	3	3	2	2
14	23	16	12	9	7	5	4	3	2	2
15	26	19	14	10	8	6	5	4	3	2
16	30	21	16	12	9	7	5	4	3	2
17	34	24	18	14	10	8	6	5	4	3
18	38	27	20	15	12	9	7	5	4	3
19	42	30	23	17	13	10	8	6	5	4
20	27	34	25	19	14	11	9	7	5	4
21	52	37	28	21	16	12	10	8	6	5
22	57	41	30	23	18	14	11	8	7	5
23	62	45	33	25	19	15	12	9	7	6
24	68	49	36	27	21	16	13	10	8	6
25	74	53	39	30	23	18	14	11	9	7
26	80	57	43	32	25	19	15	12	9	7
28	92	67	50	38	29	22	18	14	11	9
30	106	77	57	43	33	26	20	16	13	10
32	121	87	65	49	38	29	23	18	14	11
34	137	99	73	56	43	33	20	21	16	13
36	153	111	82	62	48	37	29	23	18	14
38	171	123	92	70	54	42	33	26	20	16
40	189	137	102	77	59	46	36	29	23	18
42	209	151	112	85	66	51	40	32	25	20
44	229	166	123	93	72	56	44	35	28	22
46	250	181	135	102	79	61	48	38	30	24
48	273	197	147	111	86	67	53	42	33	26
50	296	214	159	121	93	73	57	45	36	28
52	320	231	172	131	101	79	62	49	39	31
54	345	250	186	141	109	85	67	53	42	33
56	371	269	200	152	117	91	72	57	45	36
58	398	288	214	163	125	93	77	61	48	38
60	426	308	229	174	134	105	82	65	52	41
62	455	329	245	186	143	112	88	70	55	44
64	485	351	261	198	153	119	94	74	59	47
66	516	373	277	211	163	127	100	79	63	50
68	548	396	295	224	173	135	106	84	67	53
70	580	420	312	237	183	143	112	89	71	56

Area Estimations for Point Source Fires (continued

Spread distance chains	Effective windspeed, mi/h 1	3	5	7	9	11	13	15	17	19
					Acres					
72	614	444	330	251	194	151	119	94	75	59
74	649	469	349	265	205	160	126	99	79	63
76	684	495	368	280	216	169	133	105	83	66
78	721	521	388	295	227	178	140	111	88	70
80	758	549	408	310	239	187	147	116	92	73
82	797	576	429	326	251	196	154	122	97	77
84	836	605	450	342	264	206	162	128	102	81
86	876	634	471	358	276	216	170	135	107	85
88	917	664	494	375	290	226	178	141	112	89
90	960	694	516	392	303	237	186	147	117	93
92	1003	726	540	410	316	247	195	154	122	97
94	1047	758	563	428	330	258	203	161	128	102
96	1092	790	588	446	345	269	212	168	133	106
98	1138	823	612	465	359	281	221	175	139	110
100	1185	857	638	484	374	292	230	182	145	115
105	1306	945	703	534	412	322	254	201	159	127
110	1434	1038	772	586	453	354	278	220	175	139
115	1567	1134	843	641	495	386	304	241	191	152
120	1706	1235	918	698	539	421	331	262	208	166
125	1852	1340	997	757	585	457	360	285	226	180
130	2003	1449	1078	819	632	494	389	308	245	195
135	2160	1563	1163	883	682	533	420	332	264	210
140	2323	1681	1250	950	734	573	451	357	284	226
145	2492	1803	1341	1019	787	615	484	383	304	242
150	2667	1930	1435	1091	842	658	518	410	326	259
155	2847	2061	1533	1165	899	703	553	438	348	277
160	3034	2196	1633	1241	958	749	590	467	371	295
165	3227	2335	1737	1320	1019	796	627	496	394	314
170	3425	2479	1844	1401	1082	845	666	527	419	333
175	3630	2627	1954	1485	1146	896	705	559	444	353
180	3840	2779	2067	1571	1213	948	746	591	470	374
185	4057	2936	2184	1659	1281	1001	788	624	496	395
190	4279	3097	2303	1750	1352	1056	832	658	523	417
195	4507	3262	2426	1844	1424	1112	876	694	551	439
200	4741	3431	2552	1939	1498	1170	921	730	580	462
210	5227	3783	2814	2138	1651	1290	1016	804	639	509
220	5737	4152	3086	2347	1812	1416	1115	883	702	559
230	6720	4538	3375	2565	1981	1547	1219	965	767	611
240	6827	4941	3675	2793	2157	1685	1327	1051	835	665
250	7408	5362	3986	3031	2340	1828	1440	1140	906	722
260	8013	5799	4313	3278	2531	1978	1558	1233	980	780
270	8641	6254	4652	3535	2730	2133	1680	1330	1057	842
280	9293	6726	5003	3802	2936	2294	1807	1431	1137	905
290	9969	7215	5366	4078	3149	2460	1938	1535	1219	971
300	10668	7721	5743	4364	3370	2633	2074	1642	1305	1039

NOTE: Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the non-linear equations used to produce the table. Your interpolated values may differ somewhat from those given by the TI-59 calculator with CROM

APPENDIX I, continued.

Perimeter Estimations for Point Source Fires

Spread distance chains	Effective windspeed, mi/h 1	3	5	7	9	11	13	15	17	19
	Acres									
1	3	3	3	2	[illegible]	[illegible]	2	2	2	2
2	7	6	6	5	[illegible]	5	[illegible]	4	[illegible]	[illegible]
3	11	10	9	8	7	7	7	7	6	6
4	15	13	12	11	[illegible]	10	9	[illegible]	9	9
5	19	17	15	14	13	[illegible]	[illegible]	11	11	11
6	23	20	18	16	15	15	14	14	[illegible]	13
7	27	23	21	19	[illegible]	17	[illegible]	[illegible]	[illegible]	16
8	31	27	24	22	[illegible]	20	19	[illegible]	18	[illegible]
9	35	30	27	25	23	[illegible]	21	[illegible]	20	20
10	39	34	30	28	26	25	24	23	[illegible]	23
11	43	37	33	31	29	[illegible]	[illegible]	[illegible]	[illegible]	25
12	47	41	36	33	31	30	[illegible]	28	[illegible]	27
13	50	44	39	[illegible]	[illegible]	32	31	30	[illegible]	29
14	54	47	43	39	37	[illegible]	[illegible]	33	32	32
15	58	51	46	42	39	[illegible]	36	35	34	34
16	62	54	49	[illegible]	[illegible]	[illegible]	39	38	37	36
17	66	58	52	48	[illegible]	42	41	40	39	39
18	70	61	55	50	47	45	43	42	41	41
19	74	65	58	53	[illegible]	47	46	45	44	[illegible]
20	78	68	61	56	[illegible]	50	[illegible]	[illegible]	46	46
21	82	71	64	[illegible]	[illegible]	53	51	49	[illegible]	48
22	86	75	67	62	58	[illegible]	53	[illegible]	51	[illegible]
23	90	78	70	64	60	[illegible]	56	54	[illegible]	52
24	94	82	73	67	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	98	85	76	70	[illegible]	63	[illegible]	59	[illegible]	57
26	101	88	79	73	68	[illegible]	63	61	[illegible]	59
28	109	95	86	79	[illegible]	70	[illegible]	66	65	[illegible]
30	117	102	92	84	79	[illegible]	[illegible]	[illegible]	69	69
32	125	109	98	90	84	80	78	76	[illegible]	73
34	133	116	104	96	90	[illegible]	82	80	79	[illegible]
36	141	123	110	101	95	[illegible]	[illegible]	85	83	82
38	148	130	116	107	100	[illegible]	92	90	[illegible]	87
40	156	136	122	112	[illegible]	101	[illegible]	95	93	92
42	164	143	129	118	111	106	102	99	97	96
44	172	150	135	124	116	111	107	104	[illegible]	101
46	180	157	141	129	121	[illegible]	112	109	107	[illegible]
48	188	164	147	135	127	121	[illegible]	114	[illegible]	110
50	196	171	153	141	[illegible]	126	121	[illegible]	116	115
52	203	177	159	146	137	131	[illegible]	123	121	119
54	211	184	165	152	143	136	131	[illegible]	[illegible]	124
56	219	191	172	158	148	[illegible]	[illegible]	133	[illegible]	128
58	227	198	178	163	153	146	141	137	135	133
60	235	205	184	169	158	151	146	[illegible]	[illegible]	[illegible]
62	243	212	190	175	164	156	[illegible]	[illegible]	144	142
64	250	219	196	160	169	161	156	152	[illegible]	147
66	258	225	202	186	174	166	160	156	153	151
68	266	232	208	192	180	171	165	161	[illegible]	156
70	274	239	215	197	185	176	[illegible]	166	163	161

Perimeter Estimations for Point Source Fires (continued):

Spread distance chains	Effective windspeed, mi/h 1	3	5	7	9	11	13	15	17	19
	Acres									
72	282	246	221	203	190	181	175	171	167	165
74	290	253	227	209	196	186	180	175	172	170
76	297	260	233	214	201	191	185	180	177	174
78	305	266	239	220	206	197	190	185	181	179
80	313	273	245	225	211	202	195	190	186	184
82	321	280	251	231	217	207	199	194	191	188
84	329	287	258	237	222	212	204	199	195	193
86	337	294	264	242	227	217	209	204	200	197
88	344	301	270	248	233	222	214	209	205	202
90	352	308	276	254	238	227	219	213	209	207
92	360	314	282	259	243	232	224	218	214	211
94	368	321	288	265	249	237	229	223	219	216
96	376	328	294	271	254	242	234	228	223	220
98	384	335	301	276	259	247	289	232	228	225
100	392	342	307	282	264	252	243	237	233	230
105	411	359	322	296	278	265	256	249	244	241
110	431	376	337	310	291	277	268	261	256	253
115	450	393	353	324	304	290	280	273	268	264
120	470	410	368	338	317	303	295	285	279	276
125	490	427	383	353	331	315	304	297	291	287
130	509	444	399	367	344	328	317	308	303	299
135	529	462	414	381	357	341	329	320	314	310
140	548	479	430	395	370	353	341	332	326	322
145	568	496	445	409	384	366	353	344	338	333
150	588	513	460	423	397	378	365	356	349	345
155	607	530	476	437	410	391	378	368	361	356
160	627	547	491	451	423	404	390	380	373	368
165	646	564	506	466	437	416	402	392	384	379
170	666	581	522	480	450	429	414	404	396	391
175	686	599	537	494	363	442	426	415	408	402
180	705	616	552	508	476	454	439	427	419	414
185	725	633	568	522	490	467	451	439	431	425
190	744	650	583	536	503	479	463	451	443	437
195	764	667	599	550	516	492	475	463	454	448
200	784	684	614	564	529	505	487	475	466	460
210	823	718	645	593	556	530	512	499	489	483
220	862	753	675	621	582	555	536	522	513	506
230	901	787	706	649	609	581	560	546	536	529
240	940	821	737	677	635	606	585	570	559	552
250	980	855	767	706	662	631	609	594	583	575
260	1019	889	798	734	688	656	634	617	606	598
270	1058	924	829	762	715	682	658	641	629	621
280	1097	958	860	790	741	707	682	665	653	644
290	1136	992	890	819	768	732	707	689	676	667
300	1176	1026	921	847	794	757	731	713	699	690

NOTE Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the non-linear equations used to produce the table. Your interpolated values may differ somewhat from those given by the TI-59 calculator with CROM.

APPENDIX II

Notes

The five example fires cited previously (pages 8 through 19) and the four here (examples 6 through 9) have their critical values tabulated and compared to values computed for a simple ellipse using the quadratic equation approach, and for the double ellipse model using equations 2 through 9. The documented values of column 1 are obtained from reports and tables or transcribed from maps of fire growth. The perimeter, if not available, is estimated as 2.5 times the spread distance.

The simple ellipse column uses the area and perimeter values of column one in the quadratic equation (equation 13) to determine the major and minor semiaxes, a and b, of the ellipse. The total major axis dimension, 2a, is entered as the spread distance. The ration, a/b, is entered as the ℓ/w ratio.

The third column, for the double ellipse model, uses the spread distance of column 1 and applies the wind reduction factors (Albini and Baughman 1979) to the wind at 20 ft (6.1 m) to compute the average wind on the fire. These values are used with equations 2 through 9 to calculate the area, perimeter, and ℓ/w ratio values that are listed. The wind reduction factors are derived using descriptions of the fire behavior to estimate where the fire is burning into the fuel complex—surface, understory, or overstory, and from descriptions of vegetation types to determine the resistance to air movement.

The adjusted double ellipse of column 4 shows the best fit the model can make to the documented data. The ℓ/w ratio that is documented is used with figure 7 to estimate the average wind over the fire. This, along with the spread distance, is used to compute the area and perimeter of the fire. Minor adjustments to windspeed and/or spread distance may be made to improve the match to column one. This is an iterative process to try to provide insights to where the greatest uncertainties exist.

The dimensions used in the table are for spread distance in miles, windspeed in miles per hour, perimeter in miles, and area in acres. If figure 6 is used, area has to be expressed as the square of the unit used to measure the spread distance—for instance, if miles for distance, then square miles for area. Perimeter and spread distance must be measured in the same units.

Example 6. Wisconsin Fire Suppression Handbook Example, No Control. Time of event is 3 hours from start of fire. Fire is a crown fire moving over forested land, probably jack pine (*P. banksiana*).

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	3.0 hours			
Area	5,320.0 acres	5,320	5,969	5,320
Perimeter	14.0 miles	14.0	14.7	12.3
Distance	5.5 miles	6.6	6.6	5.0
Windspeed	— mi/h		12.5	8.7
ℓ/w	2.8:1	4.1:1	4.1:1	2.8:1
Time	4.0			
Area	11,200	11,200	12,560	11,200
Perimeter	20	20	21.2	18.1
Distance	7.8	9.3	9.3	7.4
Windspeed			11.9	9.1
ℓ/w	2.9:1	3.9:1	3.9:1	2.9:1

Example 7. Wisconsin Fire Suppression Handbook Example, Good Control. Time of event is 1 hour after fire start. Fire is a crown fire moving over forested land, probably jack pine (*P. banksiana*).

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1.0 hours			
Area	460.0 acres	460	588	460
Perimeter	3.5 miles	3.5	4.6	3.4
Distance	1.4 miles	1.5	1.5	1.2
Windspeed	— mi/h		7.6	5.9
ℓ/w	2.2:1	2.6:1	2.5:1	2.2:1
Time	2.0			
Area	1,300.0	1,300	1,396	1,300
Perimeter	7.5	7.5	7.8	7.5
Distance	3.2		3.6	3.4
Windspeed			14.2	14.0
ℓ/w	4.9:1	5.0:1	4.9:1	4.9:1
Time	3.0			
Area	1,900.0	1,900	1,993	1,900
Perimeter	10.0	10	10.3	10.5
Distance	4.5	4.9	4.9	5.0
Windspeed	—		16.3	17.2
ℓ/w	6.9:1	6.2:1	6.2:1	6.9:1
Time	4.0			
Area	2,200	2,200	2,291	2,200
Perimeter	12.0	12	12.2	12.3
Distance	5.6	5.9	5.9	6.0
Windspeed			18.5	19.0
ℓ/w	8.4:1	7.9:1	7.9:1	8.4:1

Example 8. The Freeman Lake Fire in northern Idaho on August 3, 1931, started in a stand of young Douglas-fir interspersed with patches of brush and grass. All dead fuels were very dry with duff and slash moisture contents under 10 percent and as low as 4 to 5 percent.

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	1030.0 to 2300.0 hours			
Area	20,000.0 acres	20,000	34,000	20,005
Perimeter	N/A miles	22.5	29.4	22.6
Distance	11.5 miles	9	11	8.4
Windspeed	14.9 mi/h	—	6.8	6.8
ℓ/w	2.3:1	2.3:1	2.3:1	2.3:1

Example 9. The Big Scrub Fire occurred in the spring of 1935 in Florida from a burning stump on muck land, but moved quickly into the crowns of the sand pine (*P. clausa*).

Variable	Documented values	Simple ellipse values	Double ellipse values	Double ellipse adj. values
Time	N/A hours			
Area	10,000.0 acres	10,000	Winds	10,000
Perimeter	36.0 miles	36	exeed	36.1
Distance	18.0 miles	18.1	range of	18.0
Windspeed	SW 60.0 mi/h		model	2.5
ℓ/w	N/A	16:1		16.5

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Anderson, Hal E. Predicting wind-driven wild land fire size and shape. Res. Pap. INT-305. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 26 p.

Documents the analysis of wind tunnel experiments on fire spread that produced a double ellipse concept of fire area growth. This provides ways of estimating size (area), shape (perimeter), and length to width ratio of a wind-driven wild land fire. The only inputs needed are estimates of the windspeed and the expected fire spread distance. Equations are available to estimate flank and backing fire rates of spread. Graphs show the relationship of wind to fire size and shape properties. Fire growth in terms of perimeter and area is available to aid fire management activities involving treatment or suppression.

KEYWORDS: fire growth, modeling, fire behavior

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Production and Product Recovery for Complete Tree Utilization in the Northern Rockies

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St Onge Logging Company of Missoula, Mont., provided skidding and loading equipment, with skilled and conscientious operators. Midnight Logging Company of Huson, Mont., provided a Melroe Bobcat feller-buncher and a skilled operator.

RESEARCH SUMMARY

Profitable management of second-growth timber in the Northern Rockies will be influenced by the economics of small timber harvesting. The small average stem size of second-growth stands coupled with low product values tends to make current logging systems uneconomical in many areas.

In this study, a whole-tree harvesting system designed to produce logs and chips was evaluated on four sites, each with a different silvicultural prescription. The system consisted of: feller-bunchers, grapple-equipped rubber-tired skidders, a tree processor, a whole-tree chipper, and a hydraulic log loader. Production rates for the overall system and for its various components were developed with time-motion study techniques. Variation in productivity between study areas was analyzed with respect to stand and site characteristics.

Results of this study indicated: (1) The system can produce chips and logs at acceptable rates for a range of site and stand conditions. Daily production ranged from 89 to 193 tons (81 to 176 tonnes) of logs and 119 to 178 tons (108 to 162 tonnes) of chips. (2) The proportions of chippable and sawable material available in the stand affect overall system productivity and productivity of system components. (3) The complete utilization of slash by the system provided additional forest management benefits. These included: reduction in bark beetle hazard, reduction of future site preparation activities (especially burning), and improved appearance of harvested stands.

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Production and Product Recovery for Complete Tree Utilization in the Northern Rockies

John M. Mandzak, Kelsey S. Milner, and John Host

INTRODUCTION

The harvest of small timber of commercial size has historically been a problem due to relatively high logging costs per unit coupled with low product values. Small logs are typically processed into studs (8-ft 2″×4″, 2″×6″, etc.). Because demand and price constantly fluctuate, the process of harvesting and conversion of small timber to studs is difficult and marginally profitable. Nevertheless, small timber represents a relatively large percentage of the volume of timber available in the Rocky Mountain area, and this percentage will increase in the coming decades as old-growth timber stands are converted to managed stands. If costs of logging small trees were reduced, the ultimate profitability of the production of framing material could be improved dramatically.

Stands of small timber are of two basic types. There is the relatively old stand, with small-diameter trees that have little potential for further net growth. Such stands occupy valuable growing space yet contribute little to site productivity. Stagnant old-growth lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and stands of true fir (*Abies* spp.) are common examples. The harvesting and subsequent regeneration of these stands, usually by clearcutting, would bring these areas back into production.

The second type of small-timber stand is the relatively young, overstocked stand with some stems of small commercial size. Partial cutting, such as a commercial thinning, would permit added growth on the remaining stems and prevent the stagnation of the first type of stand. Such partial cuts in young ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands would also help prevent buildup of bark beetle populations by maintaining tree vigor. These young, overstocked stands are of critical importance because a shortage of merchantable timber is expected after the old-growth has been harvested. The faster these young stands are brought to merchantable sizes, the shorter will be the time interval with a lower harvesting rate. It is, therefore, highly desirable that young stands are managed so as to fully utilize the growth potential of the site.

Management of small timber is also affected by the demand for wood fiber suited to the manufacture of paper, fiberboard, particleboard, or hog fuel. Historically, mill trimmings and waste have been the source of such material. However, during slack market periods when lumber and veneer production is reduced, the supply of such waste material is also reduced. Small-sized timber could help satisfy the raw material shortfall during these intervals.

This study was undertaken to explore one alternative for utilizing postlogging residues and to determine the feasibility of generating boiler fuel from thinning operations for the Forest Service and Champion Timberlands, respectively. The study took place during August 1980. It is one of a series of studies dealing with utilizing material from thinning operations in western Montana.

Study Objectives

The objective of this study was to test the feasibility of a mechanical harvesting system designed to process small logs and produce chips suitable for hog fuel and pulp and paper. The logging system is shown schematically in figure 1. Specific goals were:

1. Compare the productivity and advantages of falling and prebunching turns for grapple skidders by a feller-buncher (tree shear) relative to conventional sawyer falling, choker-skidding logging methods.
2. Compare the quality of logs manufactured by a tree processor to that for logs produced by conventional methods. Also, determine production rates for the tree processor.
3. Compare the loading time for small logs delimbed and bucked by a tree processor to those for logs decked in a conventional system.
4. Evaluate the tree processor-chipper logging system as a forest management tool. Specific tasks to be considered include:
   a. Thinning stands on a commercial basis.
   b. Clearing stands of small trees for regeneration on a commercial basis.
   c. Reducing insect damage potential in ponderosa pine stands.

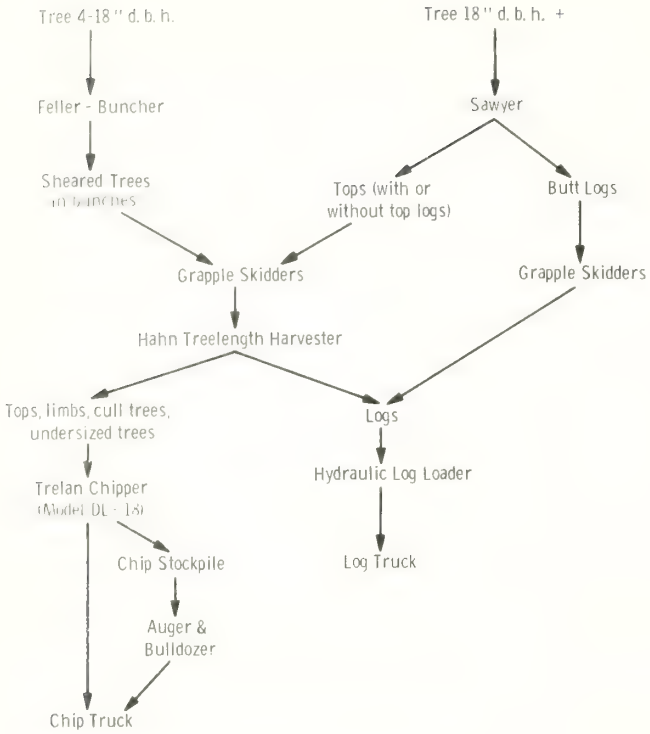


Figure 1.—Flow diagram of a harvesting system for logs and whole-tree chips (hog fuel), using a Hahn Treelength Harvester in conjunction with a Trelan Model DL-18 whole-tree chipper.

d. Eliminating slash disposal costs through 100 percent tree utilization.
e. Maintaining air quality by eliminating slash burning.
f. Improving stand access and recovering greater volume.
g. Improving esthetics of harvested areas.

STUDY METHODS

Study Area Description

Figure 2 shows the location of the four cutting blocks near Missoula, Mont. The blocks varied with respect to timber type, terrain, and cutting method, reflecting the diversity of conditions on which the logging system might be applied.

Marking, Cruising, and Block Layout

The Gold Creek lodgepole pine block was clearcut. Therefore, only the boundaries were marked. Leave trees on the remaining blocks were marked with blue paint. Rings were painted around the tree at about breast height and also just above the groundline so tree shear operators could identify the leave trees from all directions (conventional leave marking for Champion Timberlands consists of vertical blue stripes). Blocks were cruised to ensure that the stands were carefully characterized, especially with regard to stem size distribution.

Arkansas Creek block.—This 20-acre (8.1-ha) logging block was established in a young-growth stand of approximately 80 percent ponderosa pine, 15 percent Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), and 5 percent western larch (*Larix occidentalis* Nutt.). The cutting was designated a shelterwood cut. Leave trees were identified. The terrain was a flat bench with about a 5 percent slope. This stand was chosen to represent a relatively light harvest volume shelterwood cut.

The cruise summary for the block was:

Item[1]	Per acre	Per bloc
Basal area (ft^2)	99	1,98
Number – chippable stems < 9″ d.b.h.[2]	278	5,56
– saw log stems > 9″d.b.h.	85	1,70
Total trees	363	7,26
Volume – chippable trees (ft^3)	579	11,58
– saw log trees (ft^3)	1,418	28,36
– total (ft^3)	1,997	39,94
– tops of saw log trees[3] (ft^3)	112	2,24
– Scribner – 6″ top d.b.h. (bd.ft.)	4,280	85,60
– per tree (bd.ft.)	50	
Area (acres)		2

[1]See whole-tree chipping section for discussion of utilization.
[2]Except for occasional cull trees > 9″ d.b.h.
[3]Does not include limbs and needles harvested for hog fuel, not quantified due to losses during harvesting.

Gold Creek block.—This 12.7-acre (5.1-ha) logging block was established in a 70-year-old lodgepole pine stand. The species mix was approximately 98 percent lodgepole pine and 2 percent ponderosa pine. The stand was clearcut with the exception of scattered, large old-growth ponderosa pine, larch, and a few young-growth ponderosa pine of good form. The terrain was relatively flat, ranging from 5 to 25 percent on small areas of steeper ground. This block is representative of stagnant lodgepole pine stands in the Northern Rockies.

The cruise summary for the block was:

Item[1]	Per acre	Per bloc
Basal area (ft^2)	137	1,740
Number – chippable stems < 9″ d.b.h.	265	3,365
– saw log stems > 9″d.b.h.	187	2,375
Total trees	452	5,740
Volume – chippable trees (ft^3)	1,531	19,444
– saw log trees (ft^3)	3,583	45,504
– total (ft^3)	5,114	64,948
– tops of saw log trees (ft^3)	945	12,00
– Scribner – 6″ top d.b.h. (bd.ft.)	11,504	146,10
– per tree (bd.ft.)	62	
Area (acres)		12.

Sunflower Road block.—This 4.5-acre (1.8-ha) logging block was established in a young western larch stand. The species mi was estimated to be 80 percent western larch, 10 percent lodgepole pine, and 10 percent Douglas-fir. The terrain consisted of smooth slope of about 25 percent grade throughout. The bloc represented a commercial thinning of fairly light log volume or slopes near the maximum capability for conventional tree shear and rubber-tired skidders. The area also had a restricted landir area and provided an opportunity to gain experience and data on the processing of western larch.

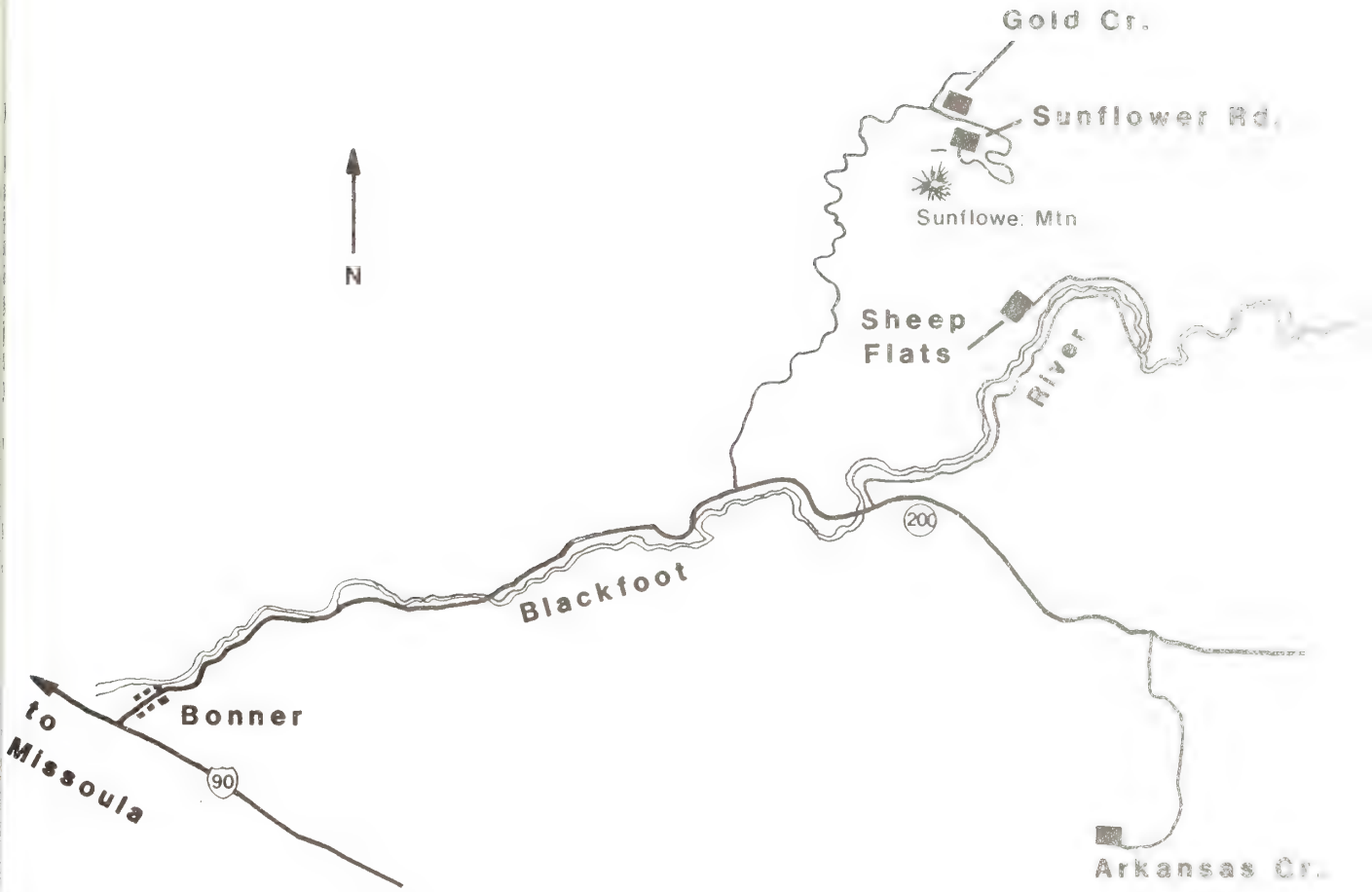


Figure 2.—Location of study blocks on Champion International lands in western Montana.

The cruise summary was:

Item[1]	Per acre	Per block
Basal area (ft^2)	147	661
Number – chippable stems < 9″ d.b.h.	441	1,984
– saw log stems > 9″d.b.h.	117	526
Total trees	558	2,511
Volume – chippable trees (ft^3)	1,610	7,245
– saw log trees (ft^3)	2,830	12,735
– total (ft^3)	4,440	19,980
– tops of saw log trees (ft^3)	496	2,232
– Scribner – 6″ top d.b.h. (bd.ft.)	11,441	51,484
– per tree (bd.ft.)	97	
Area (acres)		4.5

Sheep Flats blocks.—Three blocks were established of 17.5, 5.6, and 20 acres (7.1, 2.3, and 8.1 ha), respectively. The species mix was approximately 80 percent ponderosa pine and 20 percent Douglas-fir. Slopes were generally less than 5 percent, with the exception of about 2 acres (0.8 ha) with slopes up to 15 percent. Leave trees were marked and the dominant cutting practice was the shelterwood method with some commercial thinning. These blocks were representative of a stand with large harvestable trees that would also be attractive to conventional logging operations.

The cruise summary was:[4]

Item[1]	Per acre	Per block
Basal area (ft^2)	155	2,961
Number – chippable stems < 9″ d.b.h.	161	3,075
– saw log stems > 9″d.b.h.	129	2,464
Total trees	290	5,539
Volume – chippable trees (ft^3)	687	13,122
– saw log trees (ft^3)	2,969	56,708
– total (ft^3)	3,656	69,830
– Scribner – 6″ top d.b.h. (bd.ft.)	10,676	203,912
– per tree (bd.ft.)	84	
Area (acres)		19.1

[4]The cruise summary was for 13.5- and 5.6-acre (5.5- and 2.3-ha) units initially set up; 4 acres (1.6 ha) were added to the 13.5-acre (5.5-ha) unit. The additional areas of 4 and 20 acres (1.6 and 8.1 ha) were similar to the cruised units.

Logging Equipment and Methods

Feller-bunchers.—An International track-mounted feller-buncher (Model 3966-B) did most of the felling and bunching for the study. A Melroe Bobcat (Model 1079) feller-buncher was also used on the Gold Creek lodgepole pine and on the Sheep Flats blocks. The Bobcat shear had an accumulator to hold two or more cut stems, while the International did not. Conventional powersaws were used to fall trees 18 inches (45.7 cm) d.b.h. and larger that were too large for the feller-bunchers. Sawyers also limbed and bucked the first log out of very large trees. The bunches were not sorted according to merchantability. Bunches were oriented butt first toward the landing to facilitate skidding as shown in figure 3. Unmarked trees were sheared to a 6-inch (15.2-cm) lower d.b.h. limit.

Figure 3.—Bunched trees oriented toward landing.

Skidding machines.—Two John Deere Model 640 rubber-tired skidders were used to do the skidding. One skidder was equipped with a grapple and the other with chokers. The grapple machine operated primarily on and close to the landing, while the choker machine was used to forward bunches from the back of the units. This separation of the skidders eliminated the hazardous unhooking of chokers. Also, there was less delay with the grapple skidder at the machine-crowded landing.

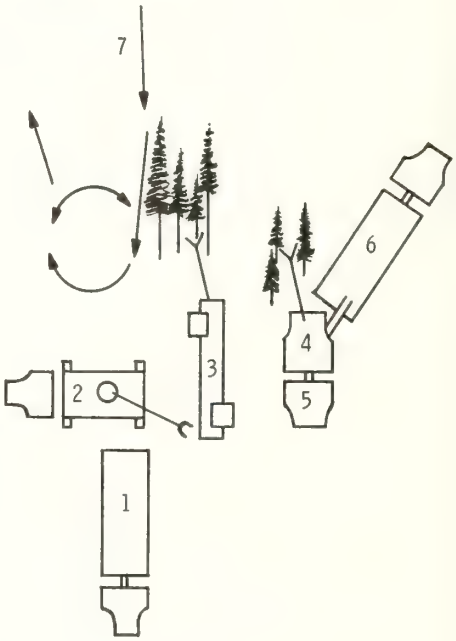
Tree processor.—The machine used was a new Hahn Tree-length Harvester equipped with two control cabs. One operator controlled the log processing while the other operator controlled the grapple, which fed trees to the processor and also helped sort bunches and feed the chipper.

Whole-tree chipper.—A Trelan Model DL-18 whole-tree chipper manufactured by Strong Manufacturing Company chipped tops and cull trees for hog fuel. This model was also equipped with a grapple loader.

Log loading.—A truck-mounted Husky Brute hydraulic loader loaded the logs produced. The loader was normally stationed next to the tree processor and sorted logs when a truck was not available.

Chip vans.—Chip vans were used to transport hog fuel chips. The vans were not disconnected from the tractors when they were filled, although this would be an option. Four types of vans were used in the study, described in appendix A. Figure 4 shows the landing on Sheep Flats block; figure 5 illustrates the landing schematically. The landing could be (and was) split up if either the tree processor or the chipper was unavailable, or if landings were too small to accommodate all of the equipment.

Figure 4.—Landing at the Sheep Flats block.



1. Log Truck
2. Hydraulic Loader
3. Hahn Harvester
4. Whole Tree Chipper
5. Truck Tractor used to move Chipper
6. Chip Van
7. Path of Skidder(s)

Figure 5.—Orientation of equipment on the landing as used in the study.

Crew Members and Organizations

Hahn Manufacturing Co. supplied two operators who had some experience with the tree processing machine. We trained the operator responsible for cutting out logs to recognize the tree species and the corresponding log lengths desired. Strong Manufacturing Co. also supplied an experienced operator for the chipper. A logger under hourly contract provided the two rubber-tired skidders, hydraulic loader, sawyer, and an operator for the International feller-buncher. The International tree shear was rented from a local equipment dealer. The Melroe Bobcat feller-buncher and operator were provided by a local contract logger. Champion Timberlands furnished data collectors, who were trained and supervised by the USDA Forest Service study coordinator. Crew supervision for the landing and woods operation was cooperative and flexible to take advantage of various ideas and skills. Most crew members were highly motivated and production conscious.

Data Collection

Time study methods.—Detailed time data were collected at each study area for the shearing, skidding, tree processing, and chipping phases of the logging system. For a sampling period the activity of each machine was timed with a stop watch to the nearest 0.01 minute and the production of each machine tallied. The sampled time for each machine was broken into two parts: that spent in active production and that spent in nonproductive activities, termed downtime. Downtime was further subdivided into categories so that causes of lost production could be identified. The data collected for each machine are described below.

Feller-bunchers.—Feller-buncher production for the tree shears was in trees cut per minute for the sample period. Merchantable and unmerchantable stems were tallied separately. The time spent cutting, the time spent moving, and the downtime were recorded. Periodically, the time spent actually cutting a given stem was recorded for a range of basal diameters. The estimated distance covered moving from stump to tree was also recorded.

Skidders.—Two persons were needed to collect skidder data, a landing observer and a field observer. At the landing the turn number, lapsed downtime, and time spent at several landing activities were recorded. Landing activities recorded included unhook time, time spent clearing the area, and time spent moving stockpiled turns closer to the tree processor and chipper. The field observer recorded lapsed time, turn number, number of trees per turn, hook time, round trip time, downtime, and skid distance. These observations were then combined on a per-turn basis to yield production rates of stems per day and time per turn.

Tree processing.—A single observer recorded lapsed clock-time, number of trees handled, number of logs produced, and downtime for the tree processor. Periodically, processing time per tree was recorded for a range of diameters and species. Production was in produced logs per minute.

Chipping.—A single observer recorded lapsed time, number of merchantable stems, number of unmerchantable stems, and downtime for the chipper by van load produced during the sample period. Tops and limbs were not counted. Production was in number of stems processed per minute or units of chips produced per unit of time. The observers also recorded arrival and departure of chip vans and log trucks and noted other activities or characteristics of the operation that affected production.

Miscellaneous.—The data collection was carried out in such a manner that:

1. Safety of all personnel was ensured.
2. Production personnel did not have to worry about the safety of study personnel.
3. The production process was not affected by the study process.

Production tallies.—Each load of logs received a receipt or "ticket book" number according to Champion Timberlands' practice. Every load of logs was weight scaled at the mill log yard. Scaling frequency (number of loads scaled versus total number of loads) varied from block to block, depending on the number of loads expected. The scaling frequency was 50 percent on the larger blocks and 100 percent on the smaller blocks. Log volume in Scribner board feet was obtained from the scaling data.

Each van load of hog fuel also received a "ticket." Net weights, gross weights, and number of "hog fuel units" were determined by standard accounting and sampling procedures at the unloading facility of a Champion International pulpmill.

Log quality.—Log quality reports were prepared in accordance with standard company procedures. Data were, therefore, available to compare logs manufactured with a tree processor to normally processed logs. Log lengths, broken ends, unsquare bucking, limbs, etc., were evaluated in such reports.

Chip quality.—Samples of chips were analyzed for properties important to papermaking. The percentage of bark content and the percentage of chips over and under a desired size range were determined. Such properties are not critical if the product is used for hog fuel.

RESULTS

System Productivity

Table 1 shows the overall production of hog fuel and logs realized from each cutting block. On a per-acre basis, production of hog fuel (tons/acre) and logs (M bd.ft./acre) varied considerably among the cutting blocks. The clearcut operation in lodgepole pine (Gold Creek) generated the highest per-acre yields of both logs and hog fuel. The partial cutting operations at Sunflower Road and Arkansas Creek generated the next highest per-acre production of hog fuel followed by the shelterwood cutting at Sheep Flats. The order of log production in the partial cuts is reversed. The Sheep Flats operation produced 50 percent more log volume than did the other partial cutting operations at Sunflower Road and Arkansas Creek.

To more accurately assess the differences in system productivity, it is useful to consider production per unit of labor rather than production per acre. Table 2 shows production rates in tons per net man-hour (net time = total time – delay time) for hog fuel and logs for each cutting block.

When productivity is based on time rather than acres, the rankings change. This is because table 2 data indicate how well the system processed the flow of raw materials per unit of labor rather than what was available per acre for the system to process.

The results in table 2 suggest that the system is most productive, in terms of total tons per man-hour, when logs are produced at a rate equal to or greater than that for hog fuel. Two factors that logically affect these rates of production are (1) raw material characteristics and (2) system component interactions.

Table 1.—Summary of study areas and production volumes

Area	Description	Species mix		Production: Hog fuel	Production: Logs
		Percent			
Arkansas Creek	20 acres (8.1 ha) Slope 4% Shelterwood Maximum skid 800 ft (0.24 km) Haul distance 65 mi (104.6 km) 5 days	PP WL DF	82 15 3	333 units 1 load/acre 25 tons/acre (56.3 t/ha)	71.1 M bd.ft. .9 load/acre 3.6 M bd.ft./acre
Gold Creek	12.7 acres (5.1 ha) Slope 4%-25% Clearcut Maximum skid 800 ft (0.24 km) Haul distance 55 mi (88.5 km) 4 days	PP LLP	2 98	426 units 1.9 loads/acre 44.4 tons/acre (99.9 t/ha)	94.9 M bd.ft. 1.8 loads/acre 7.5 M bd.ft./acre
Sunflower Road	4.5 acres (1.8 ha) Slope 25% Commercial thin Maximum skid 500 ft (0.15 km) Haul distance 55 mi (88.5 km) 2 days	WL LPP DF	90 7 3	142 units 2 loads/acre 43 tons/acre (96.8 t/ha)	17.4 M bd.ft. .9 load/acre 3.2 M bd.ft./acre
Sheep Flats	43.1 acres (17.4 ha) Slope 5% Shelterwood Max. skid 1,000 ft (0.30 km) Haul distance 70 mi (112.6 km) 9 days	PP DF	80 20	607 units 0.9 load/acre 19.4 tons/acre (43.7 t/ha)	224.9 M bd.ft. 1.2 loads/acre 5.2 M bd.ft./acre

Table 2.—Comparison of labor productivity for different logging blocks

Harvest block	Production: Fuel	Production: Logs	Production: Total	Manhours	Production rates: Fuel	Production rates: Logs	Production rates: Total
	Tons				*Tons/man-hour*		
Arkansas Creek	495	471	966	339	1.5	1.4	2.9
Gold Creek	564	608	1,172	313	1.8	1.9	3.7
Sunflower Road	193	108	300	107	1.8	1.0	2.8
Sheep Flats	903	1,349	2,252	530	1.7	2.6	4.3

With respect to the first item, table 3 shows that the most productive blocks (Sheep Flats and Gold Creek) had roughly 70 percent of the take volume in trees ≥9 inches (22.9 cm) d.b.h., and these trees accounted for 33 percent and 41 percent of the total take stems, respectively. In contrast the least productive blocks had roughly 60 percent of the take volume in trees ≥9 inches (22.9 cm) d.b.h., but these stems were only 17 percent of the total take stems. Thus, the system was least productive where the supply of saw log material was low relative to the supply of chippable material. As with other logging systems, stem size is an important productivity parameter.

Table 3.—Distribution of harvested cubic volume by size cla

Harvest block	Percent of take volume: ≥9″ d.b.h.	Percent of take volume: <9″ d.b.h.	Percent of take st: ≥9″ d.b.h.	Percent of take st: <9″d.l
Arkansas Creek	64	36	17	83
Gold Creek	70	30	41	59
Sunflower Road	60	40	17	83
Sheep Flats	72	28	33	67

The distribution of volume by size class also appeared to affect productivity of the system through its effect on the system operation. For example, the feller-bunchers could cut 5- to 15-inch (12.7- to 38.1-cm) diameter trees in approximately the same time. Thus, shearing time per cubic foot of production is higher in stands with a large proportion of small stems than in stands with mostly large stems.

The log processor and chipper were also affected by the relative proportion of large and small stems. Table 4 shows the utilization rates for both machines. In the most productive blocks (Sheep Flats and Gold Creek) the processor and chipper had utilization rates of about 70 percent. In the Sunflower block the utilization rate for the processor was only 36 percent.

Table 4.—Machine utilization[1] rates for the tree processor and chipper

Harvest block	Processor	Chipper
	Percent	*Percent*
Arkansas Creek	65	63
Gold Creek	70	72
Sunflower Road	36	71
Sheep Flats	72	70

[1]Computed from study data:

$$\frac{\text{Net time}}{\text{Gross time}} = \frac{\text{Gross time} - \text{Downtime}}{\text{Gross time}}$$

Gross time = Time under observation

While a portion of this low rate was due to lack of sawable material, a sizeable portion was due to an overabundance of chippable material. That is, the chipper could not chip the small stems fast enough to keep the landing from becoming clogged with this material. The tree processor, as a result, was forced to help feed the chipper and to spend an excessive amount of time sorting sawable and chippable material. Thus, the mix of size classes affects how efficiently the system operates and therefore affects overall productivity.

Component Productivity

Felling, bunching and skidding.—Skidding production data are shown in table 5. The lowest total daily net production was in the Arkansas Creek block, which may have been due to inexperience with the harvest system. Bunches of trees were not properly oriented with respect to the landing in this block. Total daily net production at the Sunflower block was next lowest. This may have been due to the steeper slopes (25 percent) and a relatively large percentage of small trees chipped for hog fuel.

Table 5.—Felling and skidding production

Area	Item	Tons/day[1]-block average: Hog fuel	Logs	Total
Arkansas Creek	Shears	52.7	50.1	102.8
	Skidders	120.8	114.7	235.5
Gold Creek	Shears	67.2	72.5	139.7
	Skidders	148.5	160.2	308.7
Sunflower Road	Shears	49.6	24.9	74.5
	Skidders	177.8	89.3	267.1
Sheep Flats	Shears	83.1	134.2	217.3
	Skidders	119.4	192.8	312.2

[1]Operational days = (total hours-unnecessary downtime)/8 hours

Two different kinds of feller-bunchers were employed. An International tracked (Model No. 3966-B) feller-buncher accounted for most of the volume logged in the study. The remainder of the felling was accomplished with a Melroe Bobcat (Model No. 1079) feller-buncher. Average production rates for each machine are presented in table 6. They ranged from 343 to 511 trees per day for the International and from 511 to 562 trees per day for the Bobcat.

Table 6.—Production rates for feller-bunchers (block average)

Area	Machine	Trees/day[1]	Utilization[1]
			Percent
Arkansas Creek	International	343	85
Gold Creek[3]	International	511	88
	Bobcat	612	85
Sunflower Road	International	470	86
Sheep Flats[4]	International	386	85
	Bobcat	562	81

[1]Based on the time study samples expanded to an 8-hour shift, downtime included.
[2]Utilization = (total time-downtime)/total time.
[3]The Bobcat worked on slopes less than 10 percent; the International, slopes up to 30 percent.
[4]The Bobcat was used mainly in thicker, smaller diameter portions of the stand.

Several factors affected the International tree shear production. The operator was new to this kind of work and gained experience on the Arkansas Creek block. There was a decided improvement in the orderliness and efficiency of his work in the remaining three blocks. The spacing of leave trees also was a factor, with the operator having greatest freedom in the clearcut situation. Heavy branches, which lodged in adjacent tree crowns, affected handling of the sheared trees. The size of the trees cut had little effect on the shearing and bunching time, unless the stand was so thick that several small stems could be sheared at once. Also, the International feller-buncher did not have an accumulator, so it had to lay down each tree as it was sheared.

The International shear easily felled and bunched trees up to the capacity of the shear opening; i.e., 18 inches (45.7 cm) at the ground level. The Bobcat shear had trouble with the taller trees over 14 inches (35.6 cm) d.b.h. The International shear seemed quite adequate for trees up to 18 inches (45.7 cm) at ground level, on slopes up to 30 percent. Because of its small size, the Bobcat had trouble with large trees on slopes over 10 percent. Under favorable conditions (flat ground, small stems, etc.), the Bobcat was slightly more productive than the International machine. Because the Bobcat could travel fast with a sheared stem, the operator made larger bunches, which raised skidding production.

Skidding was done by two John Deere Model 640 rubber-tired skidders. One machine was equipped with a grapple, the other with standard chokers and winch. The machines generally performed different functions, so direct comparisons of production were not possible. Time study data, however, did contain information on hook/unhook time, which provided a basis for comparison with respect to one of the factors that influences production. Table 7 gives hook/unhook times for the two skidders.

The table shows that hook time for the grapple machine was considerably less than that for the choker machine. Unhook time was more similar, though the grapple machine still required less time.

Table 7.—Hook/unhook times for John Deere skidders

Date	Location	Average hook time/turn		Average unhook time/turn	
		Grapple	Choker	Grapple	Choker
		Minutes			
8/06	Arkansas Creek	0.8	3.9	0.63	0.67
8/08	Arkansas Creek	.4		.44	
8/11	Gold Creek			.40	
8/12	Gold Creek	.99		.37	
8/15	Sunflower Road				
8/22	Sheep Flats	.24	4.72	.46	.78
8/27	Sheep Flats	.59		.33	

Tree processing.—Average production rates for the tree processor are given in table 8. Daily production rates are given in appendix B. In terms of tons of logs produced per day, the greatest average rate was attained at the Sheep Flats block, nearly 200 tons (182 tonnes)/day, and the least at the Sunflower block, less than 90 tons (82 tonnes)/day. The difference was probably due to the supply and size of saw log and chippable stems and their effect on the system balance. Based on total observed time of the tree processor, production in logs/minute ranged from 0.7 to 1.0, a difference of 144 logs in an 8-hour shift. Because of the extent and type of downtime included in the total time, these figures are difficult to compare. When all downtime is removed, however, only processing times remain and comparisons become more meaningful. Table 8 indicates that logs were processed considerably faster in the Sunflower and Gold Creek blocks than in the Arkansas Sheep Flats blocks. These differences are largely because larch and lodgepole pine can be processed faster than limby "bull pine" (ponderosa).

Table 8.—Tree processor production rates

Area	Tree processor			Whole-tree chipped
	Tons/day[1]	Logs/min[2] Total time	Logs/min[2] Net time	Tons/acre
Arkansas Creek	114.7	0.7	1.0	120.8
Gold Creek	160.2	1.0	1.4	148.5
Sunflower Road	89.3	.7	2.1	177.8
Sheep Flats	192.9	.8	1.1	119.4

[1]The operational hours (total time – unnecessary downtime) were divided into total tons of logs produced (scale tickets).
[2]Based on time study data. Total time is full observation period; net time is total time minus all downtime. Appendix A details the tree processor productivity.

The Hahn Harvester representative said our production was low. He considered one load of logs per hour a reasonable goal. At an average of 90 logs per load, this translates to 1.5 logs per minute. While the net processing rate exceeded this figure in two blocks, the gross rate was only about half that value for the rest of the blocks. The chipping operation may have slowed down the log processor. This happened in the Sunflower block, where the tree processor had to be shut down on several occasions to allow the chipper to catch up. It also happened on the other blocks when the tree processor grapple was used to segregate saw log and chippable material in the turns rather than maintaining a steady supply of tree lengths to the processor. These events were not recorded; however, a low production rate may be expected when the machine is part of a system that produces both logs and hog fuel. Appendix B presents daily tree processor productivity on both gross and net time basis. Utilization percentage is also shown. These daily figures reflect block differences, daily production problems, and the learning process during the study.

Of 99 loads of logs produced in the study, about 56 were scaled and inspected under the Champion Timberlands log quality program. Two loads produced in the first harvest block showed total log defects of 36 and 23 percent, respectively. After these two adverse reports were received, a concentrated effort was made to improve log quality by instructing the processor crew in species bucking specifications. The remaining log quality reports averaged 9.3 percent total defect. During the month of the study, log quality reports from the Champion Timberlands operations averaged 12 percent defect. Figure 6 shows the quality of delimbed logs.

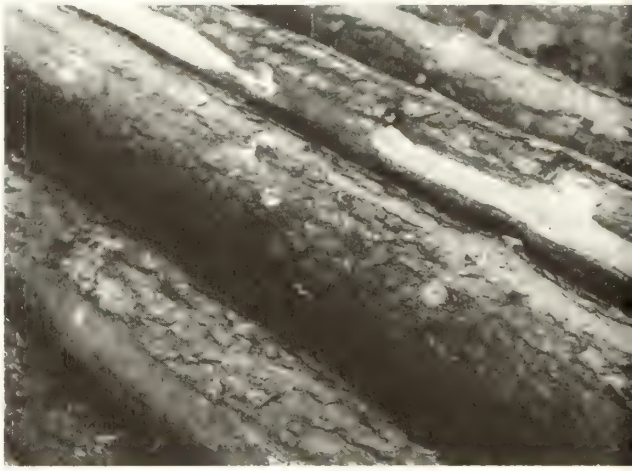


Figure 6.—Deck of delimbed study logs.

Initially, some loggers said that shearing would cause massive defects through "butt shatter" or stem crushing. Such damage was less than one-half inch on most logs. Figure 7 shows butt ends of some sheared trees. The tree butts that were substandard were trimmed by the tree processor's hydraulic chainsaw. Stem crushing might have been more severe if frozen trees were being harvested.

Some machine damage to logs can result if too much pressure is placed on the delimber knives of the tree processor. This pressure is controllable by the machine operator and should not be a problem with an experienced crew. Some "limb pull" defect was noted during the first part of the study. This defect was caused by a slow delimber knife speed that produced more of a pulling than a shearing action. A change to a high-speed sprocket drive on the delimber unit reduced the problem.

Figure 8 shows accumulated tops and limbs from the tree processor. An overaccumulation of this material plugs up the landing and requires the tree processor grapple to be used to feed the chipper.

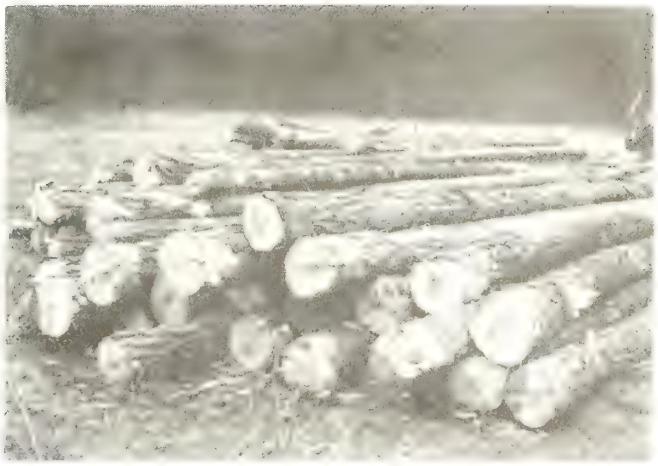


Figure 7.—Sheared logs decked for loading.

Figure 8.—An accumulation of tops and limbs from the tree processor.

Whole-tree chipping.—The average production rates in tons per day are given in table 8. A high of nearly 180 tons (164 tonnes)/day was achieved in the Sunflower block and a low of about 120 tons (109 tonnes)/day at the Sheep Flats block. Although the average utilization rates of the chipper are similar in all blocks (table 4), production rates varied considerably. (See also appendix C for daily productivity utilization.) Much of the variation was due to the kind of material chipped. In the Sunflower block and the Gold Creek block, many of the stems skidded to the landing were just under saw log size, were quite tall, and had few limbs (larch and lodgepole pine). This material produced more chips at a faster rate than the limbs and tops, which provided a greater proportion of the input of the Arkansas and Sheep Flats block.

Saw log recovery (M bd.ft./acre) was less than the preharvest cruise indicated. We attribute this to the difficulty of judging whether a small (marginal) tree will produce the minimum-sized log, especially from the cabs of the tree processor or whole-tree chipper. Apparently, the marginal trees looked smaller than they really were. For example, the Gold Creek block contained many marginal saw log stems. The cruise estimated a recovery of 11.5 M bd.ft./acre. The actual recovery was 7.5 M bd.ft./acre. Identification of marginal saw log trees may or may not be a problem, depending on the relative values of marginal logs and whole-tree chips.

The chipper used in this study was set up to produce 3/4- to 1-inch chips. Hog fuel specifications, however, allow chip thicknesses up to 2 inches (5.1 cm). The chipper operator suggested that if his machine were modified (a standard factory procedure) to produce 2-inch (5.1-cm) chips, chipping rate would be increased by 25 percent. Such an increase in chipping rate would be highly desirable in areas like the Sunflower block, where chipper capacity limited log production by the tree processor. Production of large chips could cause increased wear on the chip vans, especially on tarps or other areas that receive the full impact of blown chips.

Chip vans.—The chip vans used in this study were designed for highway use. The investigators had thought that off-highway use would require van reinforcement and that the tractors should be geared the same as log trucks. An inquiry was made as to the types of chip vans and tractors used in the Upper Peninsula of Michigan.[5] In that region, special tractor gearing or chip van reinforcement **is not** considered necessary. Apparently, there is also little significant difference in gearing systems between highway and log trucks. Log trucks utilize a slightly lower gear ratio to help them start loads moving on steep grades or soft ground. Even in the Rocky Mountains, whole-tree chipping operations would probably be conducted on reasonably gentle terrain. Also with a whole-tree logging system, skidders would be available to assist trucks. Normally, log loading occurs after skidders have stopped working in an area.

During the study, chip vans were loaded by blowing chips through the rear door. This often resulted in illegal loads due to poor weight distribution. A possible solution would be to load over the top of the van, using a U-shaped spout that would distribute the chips more evenly. Top filling would also eliminate the unfavorable orientation of the chip vans on the landing (see fig. 2). For landings of limited size without adequate turnaround space, this modification would be essential. Figure 9 shows a landing that required much less area than the landings shown in figure 4. Steep terrain limited the landing size.

[5]Personal communication with Mike Coffman, silviculturist with Champion Timberlands, Lake States Operation, Norway, Mich

Figure 9.—Landing operation on restricted steep terrain.

Log loading.—The use of a tree processor was expected to reduce the log loading time. In a conventional system, decked logs are seldom completely limbed and a landing sawyer or "knotbumper" is required to finish delimbing the logs. Loading times for logs from stands similar to those harvested in this study are typically 1 to 1.5 hours per load. Loading times for three of the study areas are given in table 9.

The table shows that load times in all areas were well under the 1 to 1.5 hours required in conventional systems. The few logs that had limbs after processing by the tree processor were delimbed by the loader operator.

Table 9.—Loading times for Hahn Harvester processed logs

Area	No. of loads	Average logs/load	Average load time
			Minutes
Gold Creek	12	84	28
Sunflower Road	4	95	31
Sheep Flats	54	55	24

Fuel consumption.—Fuel consumption data for the tree processor, chipper, and feller-bunchers are shown in table 10. These data are given because of the relative newness of this logging equipment.

Table 10.—Fuel consumption rates

Machine	Operating hours	Diesel fuel Consumption Ra		
		Gallons	*Gal/h*	*Tons/ga*
Hahn Harvester	111.6	439	3.9	5.8
Trelan chipper (Model DL-18)	111.6	884	7.9	2.4
International (Model 3966-B feller-buncher)	142.7	387	2.7	6.9
Bobcat feller-buncher (Model 1075)	77	84.7	1.1	23.8

Evaluation as a Forest Management Tool

The potential of the system to accomplish various forest management tasks was evaluated in this study. Accomplishment is evaluated in the following section.

Two tasks were: (1) feasibility of thinning stands and (2) clearing stands of small timber for regeneration on a commercial basis. Silvicultural method has little effect on the economics of this logging system. Profitability is more closely related to the balance between saw log and hog fuel production. In stands where the supply of hog fuel material was large, log production was reduced. Unfortunately, saw logs are the higher valued product, and idling of the tree processor increased costs and decreased profits.

Commercial thinning treatment is of little value if residual stand damage is high. When cutting and skidding were properly laid out, stand damage was minor and much less than conventional logging in the same stands. Where stand regeneration is desired, such as in clearcutting and seed tree cutting, the system works very well since there are few standing trees to hinder the skidding operation. In some cases, a good job of scarification to encourage natural regeneration can be achieved in the process of skidding bunches of tree-length stems. The effectiveness of the scarification will depend on several factors. We

observed that skidding of coarse-limbed ponderosa pine was more effective than skidding of finer branched species. Also, soil conditions can be critical. Certainly, skidding on frozen or snow-covered soils will produce little scarification. The Arkansas Creek block was harvested in August during a Douglas-fir seed year. Scarification was excellent. The following growing season was moist. Due to this fortunate combination of events, it appears that adequate natural regeneration has occurred. Figure 10 provides a comparison of before and after harvesting conditions on some of the harvest blocks. Slash treatment was not necessary on any of the blocks harvested.

It is a well-known fact that risk of insect attack is increased when partial cutting ponderosa pine stands, due to the improved breeding conditions for *Ips* bark beetles (*Ips pini*) in the accumulation of green slash. Whole-tree utilization definitely eliminates this problem. Only minor amounts of slash consisting of fine branches that quickly dry and become unsuitable habitat for bark beetles are left in the stand.

Whole-tree utilization eliminates piling and burning. On the experimental logging blocks, one or two slash piles on landings were burned. These were made up of fine branches, soil, and stones. It was not considered worth the damage to chipper knives to process the material.

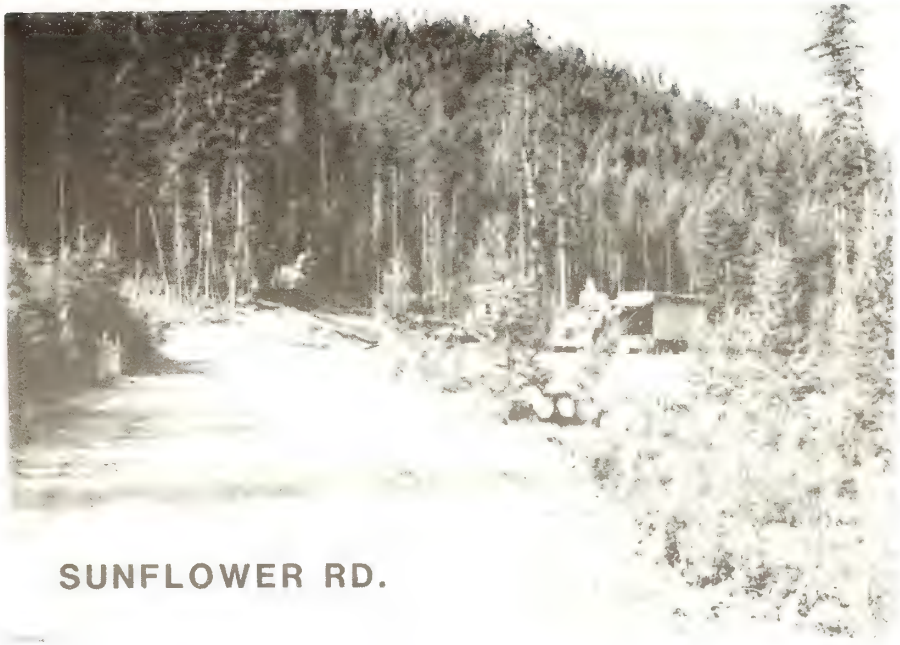
Air pollution due to slash burning is of concern in the study area. Air temperature inversions in the mountain valleys often limit the number of days when burning can be accomplished. Therefore, reduction in the total amount of material to be burned is a definite advantage for this harvest system because it reduces the cost of burning dependency on suitable weather and fuel conditions.

Stand access for current and future harvests was definitely improved by the use of feller-bunchers. The low stumps greatly reduced skidding problems. Also, smaller material that is normally pushed over during skidding was chipped for hog fuel. Elimination of the small trees also facilitated the skidding.

Visual impact of logged areas, especially along heavily traveled routes, is often a major concern. The appearance of all the blocks harvested by this system was esthetically satisfactory. This harvest system could probably be used in visually sensitive areas.

ARKANSAS CR.

GOLD CR.



SUNFLOWER RD.

SHEEP FLATS

SUMMARY AND RECOMMENDATIONS

The major reasons for this study were:

1. "Second-growth" and "small-log" harvesting costs are currently high; and new logging systems are urgently needed to handle this material efficiently and economically.
2. Methods to harvest biomass fuels and fiber efficiently and economically are also urgently needed.
3. Highly mechanized and specialized logging systems often prove to be necessary in managed stands. In the past, construction equipment with only minor modifications was sufficient to log large, high-value old growth.

The results of this study indicate that the harvest systems studied can produce a mix of hog fuel and logs at acceptable rates over a range of stand and site conditions under a variety of silvicultural prescriptions. Generally, the system is most productive (tons/man-hour) on gentle terrain in stands where the supply of sawable material is equal to or greater than the supply of chippable material. The results suggested that the system studied can operate profitably in stands where conventional systems would be uneconomical. This competitive advantage will increase as the value of small diameter material rises.

Recommendations for inclusion of this system in Champion Timberlands operation are based on:

1. Relative economics of this harvesting system compared to conventional methods.
2. The current need for wood as an alternative fuel source.
3. The place of this harvest system in overall logging programs.
4. Potential uses and abuses of the logging system.

We recommended that Champion Timberlands equip at least one crew with a tree processor, whole-tree chipper, two feller-bunchers, and two grapple skidders for a truly operational test of this harvest system. This crew should produce in excess of 15,000 units of hog fuel and 3 million board feet of logs in a 200-working-day year. Approximately 1,000 acres (404.7 ha) would be treated, yielding an average log volume of 4 M bd.ft./acre. The recommendation is assumed to be economically sound because the experimental harvest system produced logs at a favorable production rate relative to conventional logging. Also, hog fuel was produced at a cost about equal to current market prices. Within modest hauling distances, hog fuel can be produced more cheaply than hauling it from remote mill sites.

Because of terrain and weather in the Rocky Mountains, woods operations must be scheduled for areas that are suitable for summer-fall, winter, and spring logging conditions. Winter logging opportunities are confined to relatively low elevations and gentle slopes. The harvest system described in this report is limited to the same type of ground and might compete with conventional logging equipment for winter ground. This can be avoided by using the whole-tree system in stands where it has an advantage. For example, in the summer and fall, lodgepole and true fir could be clearcut on high elevation, gentle slopes. In the winter and spring, commercial thinning of ponderosa pine could be a specialty. The whole-tree harvest system has several advantages in such sites over conventional logging systems. Visually sensitive areas could also be a specialty of whole-tree logging.

Potential abuses include overthinning of stands that are being commercially thinned. Also winter game ranges could be temporarily stripped of storm shelter and forage during a commercial thinning. Perhaps whole-tree logging should be limited, as are clearcuts, to blocks under 40 acres unless large clearcuts are justified.

APPENDIX A

VOLUME AND LEGAL LOADS FOR STANDARD CHIP VAN AND TRACTOR COMBINATIONS

Trailer type	Volume	Montana legal gross weight (lb) including tractor	Estimated net weight (lb of hog fuel)	Approximate number of hog fuel units
	Ft^3			
40-foot "flat bottom"	2,600 (73.6 m^3)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "flat bottom"	3,200 (90.6 m^3)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "drop belly-tandem axle"	3,500 (99.0 m^3)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "drop belly-spread axle"	3,500 (99.0 m^3)	79,400 (36.2 t)	50,100 (22.8 t)	17.9

APPENDIX B

TREE PROCESSOR PRODUCTIVITY

Date	Location	Logs/day[1]		M bd.ft./day[1]		Utilization
		Gross time	Net time	Gross time	Net time	
						Percent
08/04	Arkansas Creek	211	312	15.4	22.7	68
08/05	Arkansas Creek	316	456	23.0	33.2	69
08/07	Arkansas Creek	417	552	30.4	40.1	76
08/08	Arkansas Creek	278	561	20.2	40.8	50
	Average	*311*	*475*	*22.6*	*34.7*	*65*
08/11	Gold Creek	581	682	28.1	32.9	85
08/12	Gold Creek	523	658	25.3	31.8	80
08/13	Gold Greek	364	619	17.6	29.9	59
	Average	*461*	*658*	*22.3*	*31.8*	*70*
08/15	Sunflower Road	278	1,334	12.7	60.8	21
08/18	Sunflower Road	360	695	30.5	58.9	52
	Average	*319*	*1,014*	*21.6*	*59.0*	*36*
08/19	Sheep Flats	576	662	48.8	56.1	87
08/20	Sheep Flats	370	504	31.4	42.7	73
08/25	Sheep Flats	389	576	33.0	48.8	68
08/26	Sheep Flats	264	451	22.4	38.2	59
08/27	Sheep Flats	370	499	31.4	42.3	74
	Average	*393*	*538*	*33.3*	*42.3*	*72*

[1]A day consists of 8 hours of production per shift.

APPENDIX C

WHOLE-TREE CHIPPER PRODUCTIVITY

Date	Location	Average minutes per HF[1] unit		Average minutes per load		Utilization
		Gross	Net[1]	Gross	Net	
						Percent
				Mean Load = 16.6 HF Units		
08/04	Arkansas Creek	7.6	5.4	127.0	90.0	71
08/05	Arkansas Creek	4.5	3.9	74.4	64.6	87
08/07	Arkansas Creek	3.3	3.1	55.0	50.9	93
	Average	*4.7*	*4.1*	*78.7*	*64.5*	*84*
				Mean Load = 17.0 HF Units		
08/11	Gold Creek	4.5	3.7	76.8	62.2	81
08/12	Gold Creek	4.6	3.4	78.0	58.0	74
08/14	Gold Creek	4.2	3.6	71.3	44.1	61
	Average	*4.4*	*3.2*	*75.4*	*54.8*	*72*
				Mean Load = 14.2 HF Units		
08/18	Sunflower Road	4.0	2.8	56.8	40.1	71
				Mean Load = 16.4 HF Units		
08/20	Sheep Flats	4.9	3.4	80.2	56.2	71
08/21	Sheep Flats	5.5	4.6	90.6	74.8	82
08/25	Sheep Flats	4.9	2.8	80.8	45.7	56
08/26	Sheep Flats	6.2	3.8	101.9	62.9	62
08/27	Sheep Flats	4.4	3.2	72.8	51.9	71
08/28	Sheep Flats	4.9	3.4	79.6	56.0	70
	Average	*5.1*	*3.5*	*84.3*	*57.9*	*69*

[1]HF = hog fuel.
[2]Net time = gross time – delay time

Mandzak, John; Milner, Kelsey S.; Host, John. Production and product recovery for complete tree utilization in the Northern Rockies. Res. Pap. INT-306. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 17 p.

Thinning operations on four different cutting blocks were monitored. The logging system consisted of feller-bunchers, grapple and choker skidders, and on the landing a whole-tree processor, chipper, and hydraulic loader. Variation in productivity among study areas was analyzed with respect to stand and site characteristics. Product alternatives and volumes were evaluated. Results indicated that (1) logs and chips can be produced at acceptable daily rates of 89 to 193 tons of logs and 119 to 178 tons of chips, (2) the proportions of saw logs and chippable material in the stand affect system productivity, and (3) complete utilization of slash provided additional benefits compatible with public and private forest management goals.

KEYWORDS: logging productivity, commercial thinning operations, product recovery

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Evaluating Slope Stability Prior to Road Construction

James L. Clayton

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THE AUTHOR

JAMES L. CLAYTON has been a research soil scientist with the Intermountain Forest and Range Experiment Station in Boise, Idaho, since 1967. In addition to his research on the relationships between rock properties and slope stability, Mr. Clayton is conducting research on stream chemistry and nutrient cycling in the Idaho batholith.

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RESEARCH SUMMARY

Subsurface bedrock properties play an important role in determining slope stability in the Idaho batholith; however, properties like degree of weathering are difficult to define prior to construction. The usefulness of seismic, resistivity, and vegetation surveys for predicting subsurface strength characteristics of granitic rock was evaluated in the Idaho batholith. Rock strength varies inversely with degree of weathering and fracture density. Rocks that have weathered or altered to the point where they contain sufficient clay to exhibit plastic properties (referred to here as highly weathered rock) are particularly susceptible to mass failure following disturbance. Eleven of twelve zones identified as highly weathered following construction were predicted by one or more surveys along a proposed road centerline. Using the same criteria, 10 other zones would have been predicted to contain highly weathered rock, but did not. Preconstruction geophysical and vegetation surveys may efficiently narrow the number of sites requiring additional surface exploration or drilling for drainage location, or locate sites requiring physical structures for road stabilization.

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Ogden, UT 84401

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Evaluating Slope Stability Prior to Road Construction

James L. Clayton

SLOPE INSTABILITY RELATED TO ROCK PROPERTIES

The Idaho batholith is a large body composed of multiple intrusions of coarse-grained granitic rock. The batholith outcrops across Idaho more or less continuously for about 250 miles (400 km) in a north-south direction, and 80 miles (130 km) east-west. Most of the land is forested and under Federal management. Eleven National Forests cover more than 80 percent of the batholith lands.

Soils in the Idaho batholith are coarse textured, cohesionless, and highly erodible. Researchers in other areas have found that granitic soils with low aggregate stability have high surface erosion potentials. André and Anderson (1961) compared the erodibility of soils formed from eight different parent materials in northern California and found granitic soils to be most erodible. Wooldridge (1964) compared soils formed from three parent materials in central Washington and also found granitic soils to be most erodible. The lack of aggregate stability directly affects surface erosion rates in unprotected soils. Potential for mass erosion is also high in the Idaho batholith, particularly after disturbance by fire or management activities such as road construction and logging. Shallow, fast-moving failures such as debris slides and debris torrents are common on granitic lands. Deep-seated, slow mass failures are generally absent.

Mass erosion in batholith areas is highly correlated with properties of the parent rock such as structure, fracture density, and degree of weathering. Clayton and others (1975) showed relationships between weathering and landslide activity in the southern Idaho batholith. Highly weathered rock is more prone to mass erosion than unweathered rock. Durgin (1977) described similar relationships between landslide activity and rock weathering on granitic soils in northern California. Megahan and others (1978), in a comprehensive study of 877 landslides in the northern and southern Idaho batholith, found that slide frequency was related to both weathering characteristics and orientation of fractures. In this study there was a tendency for landslides to be more common in highly weathered rock, but the relationship was confounded by slope steepness and an inability to correct for the areal distribution of rock weathering classes considered. For example, 12 percent of the landslides studied in the northern Idaho batholith occurred on the highest weathering class. This highly weathered bedrock is relatively rare; Gray and Megahan (1981) suggest that less than 5 percent of the batholith is comprised of such rock. Had Megahan and others (1978) been able to adjust for the actual distribution of rock types in their population, a stronger relationship between weathering and landslides probably would have emerged. There was no relationship between fracture density and landslide activity in this study; however, fractures oriented parallel to the slope were more commonly associated with landslides.

The hazard potential for mass erosion in the batholith is greatly increased following a disturbance such as logging or road construction. Vegetation removal often results in removal of a critical margin of safety afforded the soil by roots and soil arching between stems (Gray and Megahan, 1981). Changes in slope hydrology associated with interception and redistribution of subsurface flow following road construction also increase the potential for mass erosion (Gray and Megahan 1981). Jensen and Cole (1965) reported that 80 of 89 landslides occurring in the South Fork of the Salmon River in April, 1965 were associated with roads.

Most site properties that show a correlation with mass erosion hazard (for example: slope steepness, position on slope, land type, management history) are easy to recognize by a field reconaissance. Unfortunately, subsurface bedrock properties are not. In a study of rock properties in the early 1970's, Hampton and others (1974) investigated the correlation between seismic velocity and weathering properties of rock. They hoped that seismic surveys conducted on the ground surface could elucidate rock weathering properties at depth. The relationship between seismic wave velocities and weathering classes (as defined by Clayton and Arnold 1972) was obscure. Weathering classes range from 1 (hard, unweathered rock of high mechanical strength) to 7 (very highly weathered or altered, containing considerable clay; plastic when wet). For rocks with similar fracture densities, there was a trend toward decreasing seismic velocity, with an increase in the degree of weathering; however, this relationship was not strong. Clayton and others (1979) found a strong relationship between weathering class and sonic wave velocity transmitted through intact rock cores. From this it seems apparent that structural differences associated with fractures or joints obfuscate the interpretation of degree of weathering from seismic data.

Scientists working on the problem of surface detection of subsurface rock properties felt that a combination of geophysical surveys, for example seismic data coupled with resistivity data, might provide more information about subsurface conditions. The reasoning behind this is as follows: (1) Seismic wave velocity and apparent resistivity of rock are a function of velocity and resistivity of the weathered rock matrix plus the velocity and resistivity of pores (fractures and joints). (2) Within a given weathering class, the resistivity and seismic velocity values of the matrix vary over a relatively small range; however, these parameters vary widely in porous media as pore saturation varies. (3) Resistivity will be affected by partial saturation in a different manner than seismic velocity. Slight decreases from saturation will result in concomitant lowering of seismic velocity; however, resistivity will be relatively unaffected as long as there is continuous wetting of surfaces comprising the pore wall. A complete and theoretical discussion of these ideas, plus a conceptual model designed to fit granitic rock of the Idaho batholith, was provided by Fausset and others (1978).

THE STUDY

In order to explore the idea that seismic and resistivity geophysical surveys together would provide more information about subsurface conditions than either technique alone, a study was proposed in the southwestern Idaho batholith. The Silver Creek watershed (45°25′ N. latitude, 115°45′W. longitude), tributary to the Middle Fork of the Payette River, contains eight smaller drainages in which scientists are studying watershed response to a variety of timber harvesting practices. A high standard forest road to support logging and forest recreation traffic was planned in 1975. This road would run for 2.7 miles (4.4 km) through three of the small research watersheds. From previous road construction in the area, I expected the road would cross some zones of the highly weathered rock that is commonly associated with mass failures in the batholith.

The Intermountain Forest and Range Experiment Station entered into a cooperative agreement with geophysicists from Boise State University to evaluate the subsurface rock properties along the proposed road. The University agreed to conduct the geophysical surveys and make predictions about rock conditions prior to road construction. The Experiment Station agreed to classify the rock properties following construction and evaluate the geophysical surveys and predictions made prior to construction.

METHODS

Data Acquisition

Geophysical surveys were conducted along the proposed centerline of the road in the summer of 1976. Slightly more than 7,900 ft (2 410 m) of the road were examined. Seismic traverses were run using a Bison Model 1570 Signal Enhancement Seismograph[1]. A 120-ft (36.6-m) transect was centered at each 100-ft station point, with geophones placed at each end of the transect. Hammer impact points were spaced at 10-ft (3-m) intervals along the centerline, and run between the two geophones. This design allowed us to obtain reversed profiles of seismic velocity centered at 100-ft spacings along the entire proposed roadway.

The survey crew obtained resistivity profiles along the centerline at the same station centers used for the seismic work. They used a Bison Model 2350 Earth Resistivity System. The Schlumberger electrode configuration was used with a maximum total array length of 120 ft (37 m).

The road was constructed during the summer of 1980. Immediately following construction, the weathering and fracturing characteristics of all exposed bedrock were classified according to the classification system of Clayton and Arnold (1972). Exposed bedrock required the presence of a roadcut. Of the 7,900 feet (2 410 m) examined during the geophysical surveys, 5,300 feet (1 615 m) were eventually exposed by road cuts of sufficient depth to classify the rock.

Data Analysis

Seismic wave velocities were computed for two layers, and the thickness of the first layer was computed by the method of differences (Broughton-Edge and Laby 1931). The velocities of the first layer were consistent with an interpretation that this layer is soil. The first layer depth averages approximately 3 ft (1 m) and overlies a thicker zone of weathered rock with markedly higher velocities. These second layer velocities were the ones of interest and represent velocity of seismic wave travel through the bedrock below the soil.

Resistivity soundings were made using logarithmically distributed Schlumberger AB/2 spacings of 3 to 60 ft (1 to 18 m). Fausset and others (1978) synthesized lateral profiles of resistivity from equidistant soundings at AB/2 spacings of 12, 20, and 30 ft (3.6, 6.1, and 9.1 m). This allowed for greater sensitivity in interpreting lateral changes in rock properties.

The weathering and fracture density data were initially scanned by plotting weathering or fracture density class versus road centerline station numbers. Weathering characteristics are often nonuniform within a particular section of road cut. For example, pegmatite dikes of relatively fresher and less weathered rock frequently cut through highly weathered rock. Similarly, narrow shear zones of very highly altered rock of low strength often cut through less weathered rock. It is difficult to assign a single weathering class to a section of road cut where such cases occur. When plotting weathering versus centerline station number, I described occurrences of mixed weathering classes individually, and assigned a percentage to each weathering class. Granitic rock that classified as weathering class 7 and highly weathered basic dike rock were grouped together in a category termed highly weathered rock (HWR). Weathering class 7 rock exhibits the most advanced stage of chemical weathering recognized in plutonic rocks of the Idaho batholith. It is highly argillized and exhibits plastic properties when wet. The highly weathered rock category is considered most prone to slope instability when other variables such as slope and prior land use are held constant. Fracture density is difficult to evaluate in weathering classes 6 and 7 because joint sets become indistinct. Other features such as intergranular fracturing control the porosity of weathered plutonic rocks, and so fracture density information was omitted from further analysis following the initial scan.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Occurrences of HWR were evaluated by graphical analysis in two different ways. The data set consisted of geophysical survey points for which an independent field classification of rock properties could be made following road construction. This data set was plotted with seismic velocity of the second layer on the abscissa versus apparent resistivity (AB/2 = 30 ft) on the ordinate (fig. 1). Those points identified as HWR were then flagged for easy visual identification. Secondly, arithmetic mean weathering class values were computed for each geophysical station having 50 ft (15 m) of classifiable rock on each side of the station center. (Many stations did not meet this criterion because there was no road cut.) These mean values were based upon the linear extent of each class included in this 100-ft (30-m) section. These values were plotted versus apparent resistivity, second layer seismic velocity, and the product of resistivity times seismic velocity. Visual inspection of these three graphs showed such poor correlations that further regression analyses were not attempted. The mean weathering class values were not well distributed; 90 percent of the points fell within the range 5.5 to 6.5.

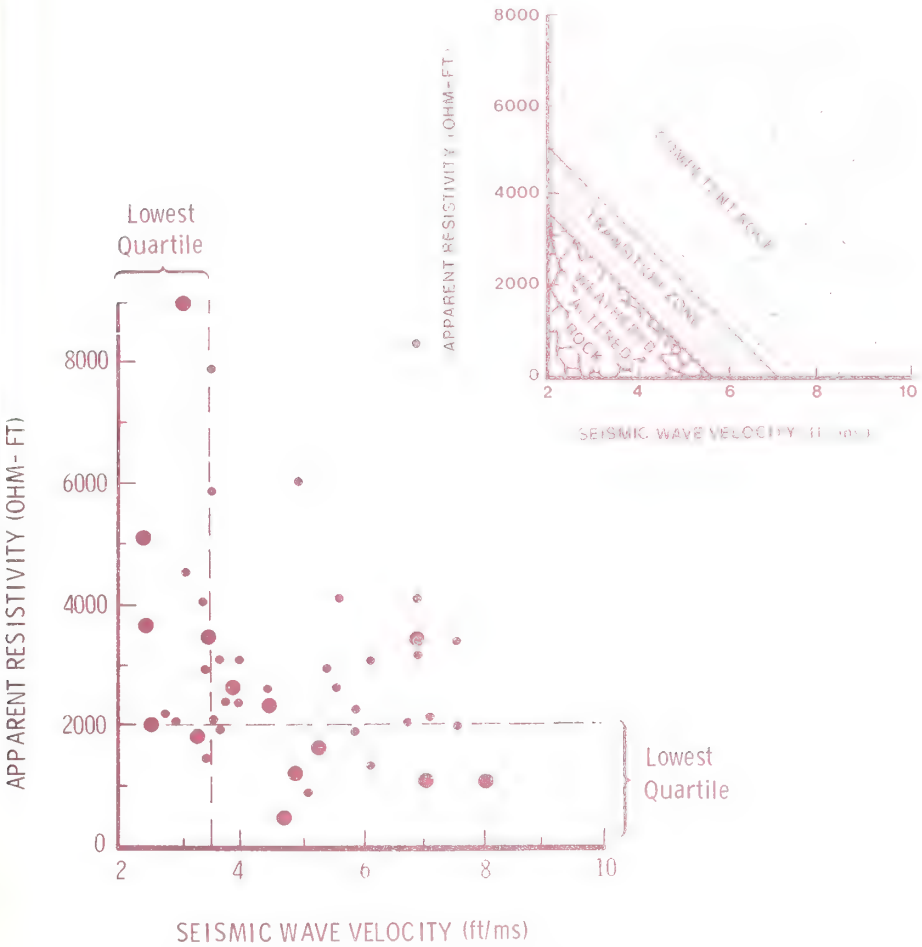

Figure 1. Scattergram of apparent resistivity versus seismic velocity of the second layer. Larger circles were identified in the field as zones of highly weathered rock. Lowest quartiles of resistivity and seismic velocity are identified on the graph. The inset depicts the zones of rock competence interpreted by Fausett and others (1978) on the basis of the seismic and resistivity data.

Results

Table 1 summarizes the location, percent, and type of highly weathered rock encountered during the survey, and indicates the usefulness of each geophysical method for predicting HWR. Of the 5,300 ft (1 615 m) of exposed rock examined, 360 ft (110 m) were classified as highly weathered. This suggests that slightly less than 7 percent of the rock in the study area might fit into the highly weathered category, a high percentage for the Idaho batholith.

Nearly 75 percent of the exposed rock was weathering class 6. Weathering class 6 rock has very low mechanical strength (Clayton and others 1979), but lacks the plastic nature of class 7 rock that results from intense chemical alteration to clay minerals. Weathering class 5 rock, which is more competent than class 6, constitutes 13 percent of the exposed rock. Class 5 rock will spall and readily decompose to grus following exposure due to road cutting. The remaining 5 percent is in weathering classes 2, 3, and 4. None of these weathering classes is extensive. A 20-ft (6-m) section of road between stations 65 and 66 in weathering class 2 required blasting.

In general, the rock along the road could be characterized as a well weathered, coarse-grained quartz monzonite (classes 5 and 6), with periodic occurrences of highly weathered, argillized rock (class 7), and some short zones of harder, more competent rock (class 2, 3, and 4).

The category HWR includes four basic dikes intruded into the granitic rock. Such dikes are not uncommon, generally are highly altered or weathered, and often contain smectite clays (Clayton 1974). Basic dikes make up 46 percent of the total rock included in the HWR category along this road.

The initial results of the two geophysical surveys published by Fausett and others (1978) included a preliminary interpretation of subsurface rock properties. Based on seismic and resistivity data, they grouped the rock into three zones: competent, transition zone, and weathered or altered (fig. 1, inset). Their weathered or altered grouping corresponds to class 7 rock of Clayton and Arnold (1972). Within each zone, the authors further selected data points based upon association with data from adjacent stations. For example, if a very low resistivity reading seemed to be associated with a shallow water table (viz., near a stream crossing), and adjacent data points had correspondingly higher resistivity values, the point with low resistivity would not be predicted to be highly weathered. Using this system, the authors predicted 67 percent of the data points in the weathered and altered zone and 9 percent in the transition zone would prove to be highly weathered rock. They predicted that no points in the competent rock zone would be highly weathered. From the postconstruction survey, the actual percentage of rock classified as highly weathered for each zone is: (1) weathered and altered, 50 percent; (2) transition, 46 percent; (3) competent, 20 percent.

The prediction method of Fausett and others (1978) excluded points of high seismic velocity and very low resistivity, or vice versa from their predicted highly weathered zone. It is apparent from figure 1 that such points may indicate zones of high weathering. Excluding these areas accounted for 4 of the 5 points that made up the 20 percent HWR in their competent zone.

Table 1.—Location, type, and extent of zones containing highly weathered rock. X[s] indicates the presence of highly weathered rock based on results from one or more preconstruction surveys[1]

Location				Recognized from preconstruction survey		
Station	to	Station	Percent and Type	Seismic	Resistivity	Vegetation
40 + 80		42 + 45	2% W7[2], W6 matrix	x		
59 + 66		60 + 00	100% W7			x
63 + 65		63 + 85	100% W7, basic dike		x	
68 + 20		68 + 80	Clay-rich colluvium	No preconstruction indication		
69 + 50		70 + 25	100% W7, basic dike		x	x
70 + 25		72 + 70	5% W7, W6 matrix		x	
73 + 40		73 + 75	100% W7		x	
77 + 10		77 + 30	100% W7, shear zone	x	x	
77 + 70		78 + 00	100% W7	x	x	
95 + 40		96 + 65	2% W7, W6 matrix	x		
103 + 55		103 + 85	100% W7, basic dike			x
110 + 75		111 + 15	100% W7, basic dike	x		

[1]Lowest quartile of seismic or resistivity values; see text for method used to interpret vegetation survey.

[2]W7, W6: weathering class according to classification system of Clayton and Arnold (1972).

Evaluation

How useful were the geophysical techniques for predicting zones of HWR? Nine of the twelve zones of HWR rock identified in table 1 were flagged by low seismic velocity and/or resistivity values (lowest quartile). One of the three zones missed is an accumulation of clay-rich colluvium in a topographic hollow, similar to the wedge soils that Dietrich and Dunne (1978) describe in the Coast Range of Oregon. The actual condition of the bedrock underlying the colluvium at this site is unknown. This site was classified in the transition zone by Fausset and others (1978).

One of the other sites was also classified in the transition zone, but the third site had a resistivity value in excess of 4,000 ohm-ft and a seismic velocity greater than 5,500 ft/s. From the geophysical data one would expect this to be the location of some of our more competent rock. There is a 40-ft (12-m) exposure of altered basic dike material at this location.

One other survey to predict rock competence prior to road construction was explored. Vegetation along the entire proposed centerline was mapped according to the subsequently published habitat type classification for central Idaho by Steele and others (1981). This system is intended to classify the ecological potential of a site to support a particular vegetation mosaic. Thus, habitat types are good indicators of moisture availability, and possibly soil depth and/or subsurface weathering conditions. Habitat types are named by the overstory present at climax and one or two characteristic understory species. The overstory species along the road are either in the drier Douglas-fir series (*Pseudotsuga menziesii*) or in the more moist grand fir series (*Abies grandis*).

I had not hypothesized any relationships between habitat types and bedrock but expected that the more moist grand fir series might be indicative of greater depths and more intensive weathering. At lower elevations at the bottom of the watershed, the more shaded portions of the road are all in the grand fir series. After climbing to midslope elevations, the predominant habitat types are in the Douglas-fir series; however, interspersed here are five short (less than 200 ft [60 m])sections of grand fir series. These sections of grand fir cannot be explained on the basis of proximity to surface water, or topographic or aspect changes. Three of these five sections are locations of HWR (table 1).

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. Using the criteria of low resistivity (<2,000 ohm-ft), low seismic velocity (<3,500 ft/s), and an atypical change in habitat type, 11 of 12 zones of HWR were identified prior to road construction.
2. Using the same criteria, 10 other zones would have been expected to contain HWR but did not. Although this is a high percentage of false-positive findings, it still greatly delimits the number of zones requiring further exploration during or prior to construction and may prove cost effective.
3. Several design features such as underdrain installation were incorporated into the road on the basis of the preconstruction surveys. The number and location of underdrains is normally difficult to predict without preconstruction data, but drainage design was predicted quite accurately on the study road.
4. Prior road construction in the vicinity of the study road suggested that HWR would be expected along the study road. Thus the predictive value was diminished for this job. Preconstruction surveys should prove more valuable in areas where little prior road construction has taken place.
5. A field review of the geophysical survey results is necessary to eliminate areas such as live stream crossings or surface springs that appear to be zones of HWR.
6. This is an evolving methodology. The methods have promise, but more tests are required to improve the predictive capabilities of geophysical and vegetation surveys.

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The usefulness of seismic, resistivity, and vegetation surveys for predicting subsurface strength characteristics of granitic rock was evaluated in the Idaho batholith. Rock strength varies inversely with degree of weathering and fracture density. Rocks that have weathered or altered to the point where they contain clays (referred to here as highly weathered rock) are particularly susceptible to mass failure following disturbance. Eleven of 12 zones identified as highly weathered were predicted by the surveys along a proposed road centerline. Using the same criteria, 10 other zones would have been predicted to contain highly weathered rock, but did not. Preconstruction geophysical and vegetation surveys may efficiently narrow the number of sites requiring additional surface exploration, or drilling for drainage location, or location of sites requiring road stabilization structures.

KEYWORDS: road contruction, slope stability, geophysical studies, seismic surveys, resistivity surveys

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Effect of Western Spruce Budworm on Douglas-fir Cone Production in Western Montana

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RESEARCH SUMMARY

Douglas-fir cone production under various western spruce budworm defoliation conditions was examined in six stands west and six east of the Continental Divide in western Montana. The stands were stratified into two general defoliation levels: heavy, where defoliation and budworms were evident on over 50 percent of the trees; and light, where defoliation and budworms were not evident on the trees. Six dominant or codominant cone-producing trees were subjectively chosen at each site. Average cone production usually was higher in lightly defoliated stands. Comparison of cone production of individual trees and sites was not practical because of the large amount of variation in cone production observed between trees within stands and between stands within the infestation levels. Attempts to relate cone production to defoliation were not successful due to the variation in cone production and problems in accurately assessing past defoliation.

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Effect of Western Spruce Budworm on Douglas-fir Cone Production in Western Montana

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NTRODUCTION

Western spruce budworm (*Choristoneura occidentalis* Free-ıan) larvae feed primarily on the current year's foliage of :veral host tree species including Douglas-fir (*Pseudotsuga ıenziesii* var. *glauca* [Beissn.] Franco), grand fir (*Abies grandis* Dougl. ex D. Don] Lindl.), subalpine fir (*Abies lasiocarpa* Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex ngelm.), and western larch (*Larix occidentalis* Nutt.) (Johnson nd Denton 1975). Budworm larvae also feed on developing nd immature cones of Douglas-fir (Dewey 1970), western larch Fellin and Shearer 1968), grand fir, subalpine fir, white fir *Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), ngelmann spruce, and white spruce (*Picea glauca* [Moench] oss) (Hedlin and others 1980).

The amount of seed disseminated into cutover areas or col-cted for artificial regeneration depends on both the number of ones produced and the extent of damage to cones and seed. A eliable estimate of the effect of budworm larvae on cone pro-uction, based on the level of defoliation, would help land ıanagers decide whether to use natural or artificial means of eforestation.

The objective of this study was to examine the impact of vestern spruce budworm larval feeding on Douglas-fir cone roduction.

METHODS

Study sites were selected in 1978 and 1979 in western Mon-ana within the *Pseudotsuga menziesii/Calamagrostis rubescens* ıabitat type (Pfister and others 1977) west of the Continental Divide, and from the more general Douglas-fir forest series east f the Continental Divide. The sites were stratified, based on round observation, into two arbitrary defoliation classes: (1) heavy—budworm feeding on the foliage was evident on over 50 percent of the trees in the stand, and (2) light—budworm feeding on foliage was not evident. Three heavily defoliated and three lightly defoliated stands were selected both east and west of the Continental Divide (fig. 1).

Six dominant or codominant cone-producing Douglas-fir trees were subjectively chosen to sample at each site. Sampling was limited to 72 trees because of time constraints. Sample tree selection was restricted to trees whose tops were within the 53-ft (16-m) reach of a truck-mounted hydraulic bucket that was used to collect branch samples.

Ten sample branches from each tree were collected from a 10-ft (3-m) section in the crown of each tree beginning 5 ft (1.5 m) below the top—similar to the procedure used by Roe (1967). Dominant cone-producing branches were selected from all sides of the crown. On trees with fewer than 10 cone-producing branches, other dominant branches within the 10-ft (3-m) sample section were selected at random. Persistent cones, persistent peduncles (the stem attachment of the cone to the twig), and cone/peduncle scars were all tallied as "cones" for the cone crops occurring from 1974 (1973 growth) to 1979 (1978 growth). The cone/peduncle scars were differentiated from flower scars by the presence of a more prominent cone axis scar. The cones, peduncles, and scars were dated according to their internodal location on the branch. "Cones" were tallied by the year of occurrence for each of the 10 branches from each sample tree.

Average defoliation per sample tree was obtained by examining past internodes and expressed as "light" (0–37.5 percent), "moderate" (37.6–62.5 percent), or "heavy" (>62.5 percent) (Robinson and others 1978). Ratings were obtained for the entire tree from the 10 branches of each tree. The 1973 to 1979 internodes were rated (1974 cones occurred on 1973 foliage).

Figure 1.—Location of study sites in western Montana.

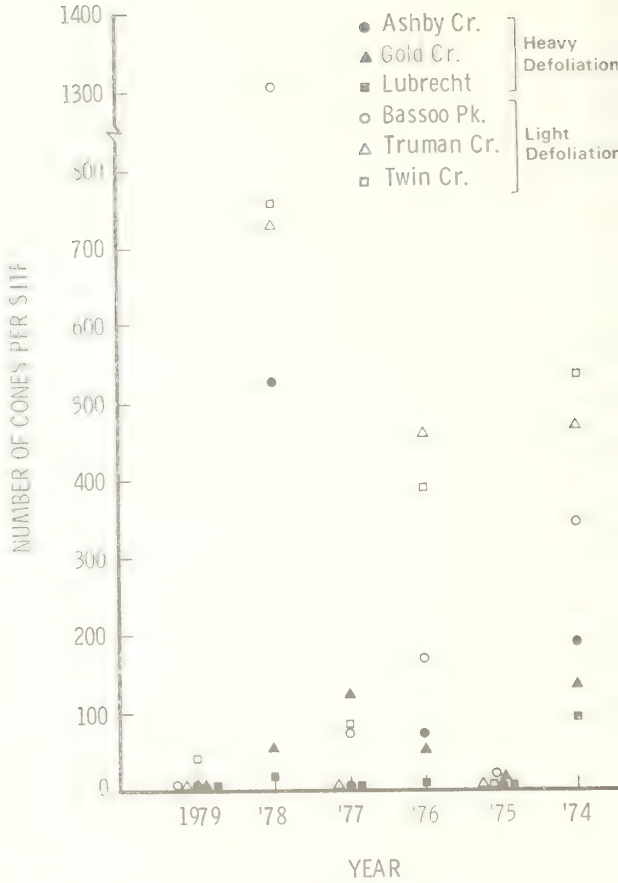

Figure 2.—Cone production west of the Continental Divide, estimated from 6 trees per site, 10 branches per tree.

RESULTS AND DISCUSSION

West of the Continental Divide, trees produced better cone crops in 1974, 1976, and 1978 than in 1975, 1977, and 1979 (fig. 2). Greater cone production occurred on trees growing within lightly defoliated stands compared to heavily defoliated stands in 1974, 1976, and 1978.

Cone production in stands east of the Continental Divide was usually lower and less uniform (fig. 3). Cones were produced in 1974 on all sites, but two of the highest cone-producing trees were located within heavily defoliated areas. Sample trees within the lightly defoliated stands produced again in 1977. In 1978, cones were produced at Thunderbolt Creek and Magpie Gulch. At Magpie Gulch, one of the six trees probably escaped serious budworm larval feeding on developing flowers and conelets and produced 86 of the 88 cones counted. In 1977 all of the lightly defoliated sites produced more cones than the heavily defoliated sites. In 1974 the heavily defoliated sites, as a whole, outproduced the lightly defoliated sites. These data support Boe's (1954) conclusion that good cone crops occurred at different times east and west of the Continental Divide. The time period covered by this study, however, was too short to adequately assess the comparative frequencies of good cone crops.

The Wilcoxon-Mann Whitney test (Wonnacott and Wonnacott 1972) substantiated the differences in cone production between infestation levels. Cone production in 1974, 1976, and 1978 west of the Continental Divide was significantly higher (99 percent confidence) in the lightly defoliated stands compared to heavily defoliated stands. East of the Continental Divide significantly more cones were produced in 1977 and 1978 in the lightly defoliated stands compared to the heavily defoliated stands. However, the reverse was true in 1974 when heavily defoliated sites outproduced lightly defoliated sites (90 percent confidence).

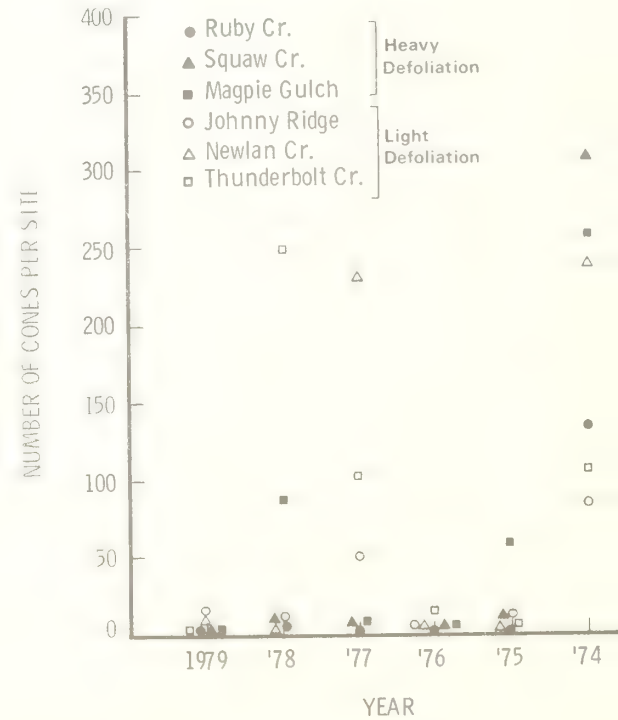

Figure 3.—Cone production east of the Continental Divide, estimated from 6 trees per site, 10 branches per tree.

There was considerable va[illegible] in mean cone production among trees on a given site (table 1).

Defoliation ratings for the [illegible] Divide were averaged for 1976, 197[illegible] were the years most likely to [illegible] principles established through [illegible] 1969, 1973), and Allen and Owens [illegible] rm spruce budworm feeding in 197[illegible] ut also developing conelets; defoli[illegible] hotosynthetic capacity [illegible] eproductive bud developme[illegible] defoli[illegible] ided unfavorable conditions [illegible] tion, resulting in more vegetative buds or aborted bu[illegible] stimates were generally high on all [illegible] atural needle mortality [illegible] ble variation in [illegible] efoliation existed within and amo[illegible]

At the lightly defoliated B[illegible] efoliation ranged from 20 to 45 percent on the samp[illegible] ome causal agent other than budw[illegible] sponsi-le for defoliation at Bassoo Peak i[illegible] pupae [illegible] bing was found and no defoliation occurred in [illegible] of 1977 foliage was observed in [illegible] This sloughing appeared be budworm related and indicated that the 1976 defolia-[illegible] eak, defoliation values [illegible] n the 1976 and 1977 foliage ratings, or Twin Creek, values were recalculated based on the 1976 78 foliage ratings. The values were then compared to defoliation of the other stands. After these adjustments the defoliation estimates for lightly defoliated [illegible] causes of the defolia-[illegible] lt it best to use the original [illegible]

[illegible] ation values were also calculated for the stands [illegible] al Divide (table 3). Because 1977 was the [illegible] in which cone production occurred in most of [illegible] liation was averaged for 1976 and 1977. Cone production east of the Continental Divide was not directly related to mean defoliation as measured in this study (fig. 5).

Table 1.—Mea[illegible] vest and east of the Con[illegible]

Defoliation and location	1976 site	1976 tre[illegible]	1976 [illegible]	1977 site	1977 tre[illegible]	1977 [illegible]	Twin site	Twin Mean tre[illegible]	Twin S.D.
[illegible] Continental D[illegible]									
HEAVY									
Ashby Creek	532	[illegible]	[illegible]	74	12.3	23.0	193	32.2	21.9
Gold Creek	53	[illegible]	8.0	51	8.5	6.2	137	22.8	9.8
Lubrecht	16	2.7	6.0	2	0.3	0.8	97	16.2	9.2
LIGHT									
Bassoo Peak	1,31[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29.4	352	58.7	50.8
Truman Creek	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	120.0	479	79.8	41.2
Twin Creek	[illegible]	127.5	55.8	[illegible]	66.0	56.4	546	91.0	51.4
East of Continental Divide									
HEAVY									
Ruby Creek	[illegible]	[illegible]	1.6	[illegible]	0.0	0.0	[illegible]	22.5	32.7
Squaw Creek	[illegible]	[illegible]	[illegible]	[illegible]	1.2	[illegible]	312	52.0	38.6
Magpie Gulch	[illegible]	14.7	5.0	[illegible]	1.2	1.6	262	43.7	23.9
LIGHT									
Johnny Ridge	[illegible]	1.3	2.8	49	8.2	17.7	[illegible]	14.0	10.1
Newlan Creek	2	0.3	0.8	234	39.0	32.9	243	40.5	35.5
Thunderbolt Creek	252	42.0	4.3	104	17.3	33.8	107	17.8	9.0

Table 2.—Mean defoliation for sample trees west of the Continental Divide, 1976 - 1978

Defoliation and location	Tree	Mean	S.D.
		Percent	
HEAVY			
Ashby Creek	1	68.3	22.4
	2	59.6	29.7
	3	81.3	17.0
	4	72.1	27.4
	5	54.6	36.7
	6	80.0	24.7
Gold Creek	20	54.2	35.3
	21	55.8	27.8
	22	55.0	27.2
	23	45.0	27.2
	24	84.6	9.1
	25	82.5	13.4
Lubrecht	68	65.4	36.1
	69	69.5	32.6
	70	85.8	30.0
	71	82.5	8.6
	72	95.8	37.1
	73	65.4	12.5
LIGHT			
Bassoo Peak	7	37.9	38.6
	8	43.8	41.2
	9	40.0	45.4
	10	42.9	39.8
	11	28.3	27.3
	12	30.4	35.5
Truman Creek	13	9.6	11.7
	14	12.1	10.6
	16	15.0	12.9
	17	14.6	17.7
	18	9.2	16.1
	19	12.1	15.9
Twin Creek	62	23.7	16.2
	63	15.4	16.3
	64	19.6	17.9
	65	31.2	22.0
	66	20.4	18.7
	67	15.4	18.5

Table 3.—Mean defoliation for sample trees east of the Continental Divide, 1976-1978

Defoliation and location	Tree	Mean	S
		Percent	
HEAVY			
Magpie Gulch	50	37.5	30
	51	42.5	2
	52	60.0	26
	53	71.3	2
	54	97.5	5
	55	75.6	27
Ruby Creek	26	53.8	28
	27	78.1	19
	28	42.5	28
	29	48.8	23
	30	45.0	28
	31	47.5	31
Squaw Creek	38	73.1	23
	39	48.8	31
	40	88.1	10
	41	51.9	32
	42	33.8	26
	43	60.6	28
LIGHT			
Newlan Creek	44	32.5	23
	45	51.3	27
	46	20.0	11
	47	41.3	27
	48	24.4	17
	49	45.0	25
Johnny Ridge	32	43.1	28
	33	33.3	30
	34	32.5	24
	35	23.8	25
	36	35.0	29
	37	48.1	27
Thunderbolt Creek	56	48.1	32
	57	51.3	32
	58	39.4	29
	59	62.5	30.
	60	23.8	25.
	61	27.5	18.

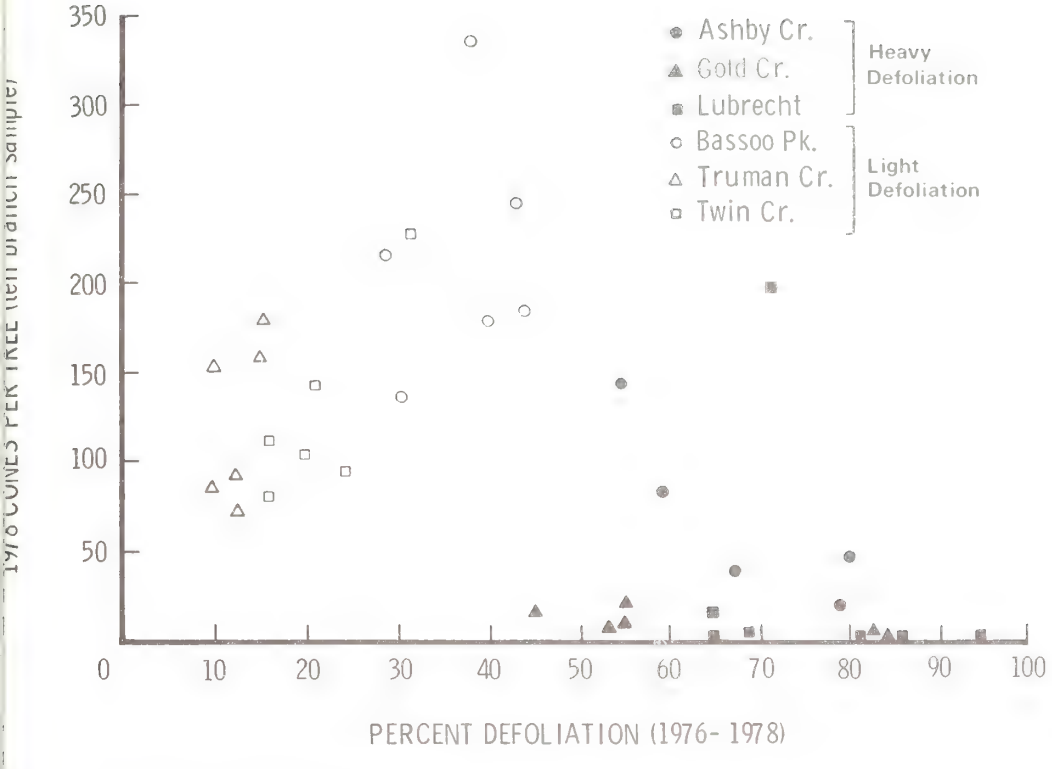

Figure 4.—Cone production and average defoliation west of the Continental Divide.

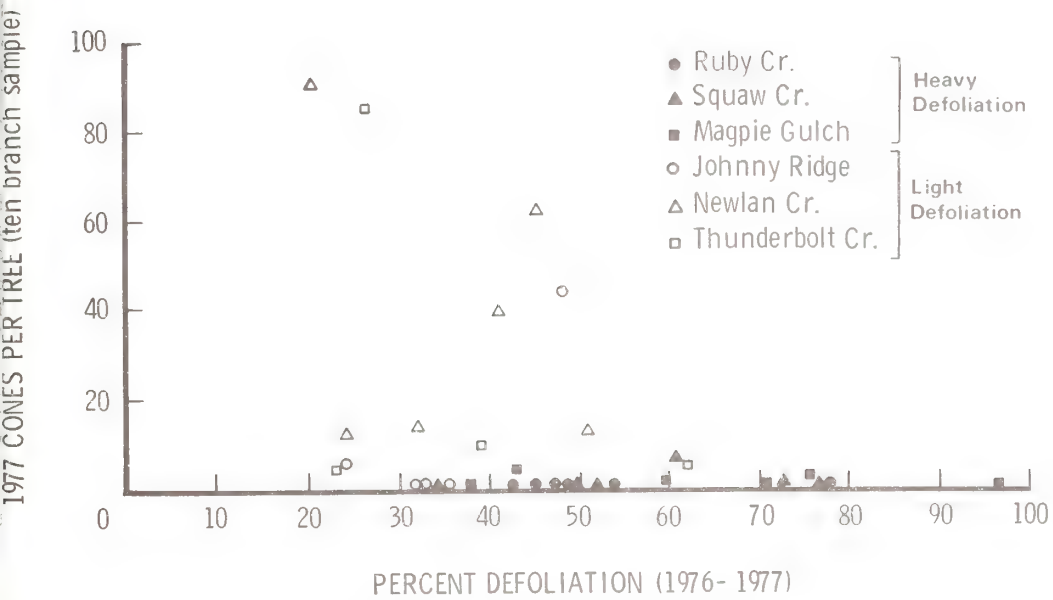

Figure 5.—Cone production and average defoliation east of the Continental Divide.

These results indicate that western spruce budworm can decrease Douglas-fir cone crops through the combined effects of direct feeding on reproductive buds and general defoliation. The magnitude of these losses is not known. If normal production for 10 branches for 6 trees/site west of the Continental Divide was 750 cones in 1978 as it was at Twin Creek and Truman Creek, losses in relatively young and vigorous stands with moderate to heavy defoliation similar to Ashby Creek would approximate 30 percent. Losses in heavily defoliated and less vigorous stands such as Gold Creek and Lubrecht could approach 90 to 95 percent; however, due to the large amount of variation between trees and sites, these must be considered only as rough estimates.

It was impossible to distinguish between the losses due to failure of reproductive bud differentiation caused by stress from defoliation and the losses due to budworm feeding during the early stages of bud burst and flower development. An attempt was made to count not only persistent cones, peduncles, and cone scars, but also to tally latent buds and dead reproductive buds and flowers for a comparison of the number of reproductive structures initiated; this is similar to the procedure used by Schooley (1978). This method did not work because the dead flowers were not persistent and latent buds were too numerous and small to be recorded with accuracy. In normal stand conditions, the separation between losses to defoliation stress and losses to feeding may not be important. But if seed were needed, individual trees could be sprayed to prevent budworm damage to flowers and cones.

In determining average defoliation for each year, 10 defoliation samples from each tree were inadequate; 20 samples did not improve the estimated mean, standard deviation, or coefficient of variation. The present method using rating codes applies discrete values to a continuous variable. This is confounded by the haphazard feeding patterns of the budworm. Not only does the intensity of defoliation change throughout the crown, defoliation is not necessarily consistent within a branch. Consequently, relatively large standard deviations were associated with low to moderate mean defoliation levels (<60 percent) for the trees west of the Continental Divide. Heavy defoliation levels (>60 percent) resulting from more uniform and severe attacks generally had smaller associated standard deviations and lower coefficients of variation (<40 percent), indicating a better estimate. Some other descriptor may be more appropriate and in fact essential for reliability in low to moderate defoliation conditions.

The importance of the duration of defoliation is suggested i the differences in cone production between the more recently defoliated Ashby Creek site and the historically defoliated Lubrecht and Gold Creek sites. To study the effects of the duration of defoliation on cone production, a more complete tree-to-tree history is necessary.

The large amount of variation in cone production at all leve of the sampling hierarchy—between branches within trees, between trees within sites, between sites within infestation levels, and between infestation levels within a general geographic region—rendered traditional sampling systems almost useless. This, coupled with the other factors that control cone production—such as weather (Lowry 1966; vanVredenburch and LaBastide 1969; Eis 1973), genetic difference (Eis and others 1965; Griffith 1968), carbohydrate levels (Kramer and Kozlowski 1960; Eis and others 1965; Kozlowski 1971; Ebell 1971), an levels of growth hormones (Ross and Pharis 1976; Pharis and Kuo 1977)—prevented any reliable means of isolating the budworm's impact on cone production.

Based on these results, if accuracy to within ± 10 percent of the true mean with 95 percent confidence is required for estimates of cone production, 100 percent sampling of the cone branches per tree would have been necessary. Sampling of this intensity is unrealistic in most studies. Consequently, the researcher should be ready to accept the large amounts of inherent variation or develop a more effective sampling method.

The results from this study show that western spruce budworm infestations caused lower Douglas-fir cone production i several stands west of the Continental Divide in Montana. Results from further cone production studies will be enhanced by understanding: (1) the factors affecting cone production such that budworm damage within and between trees can be isolated for site comparisons; (2) the effect of defoliation (bot amount and duration) on cone production, including a more accurate description or estimator of defoliation; and (3) the decrease in cone production due to direct larval feeding or to defoliation stress.

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Chrisman, Allen B.; Blake, George M.; Shearer, Raymond C. Effect of western spruce budworm on Douglas-fir cone production in western Montana. Res. Pap. INT-308. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 7 p.

Douglas-fir cone production in stands of heavy or light western spruce budworm defoliation conditions was examined at 12 western Montana study sites on 72 trees. Average cone production was usually higher on sites where budworm defoliation was light compared to heavily defoliated stands. Attempts to analyze cone production of individual trees and sites were unsuccessful because of the large amount of variation in cone production between trees within sites and between sites within the infestation levels.

KEYWORDS: cone production, defoliation, Douglas-fir, *Pseudotsuga menziesii* var. *glauca*, western spruce budworm, *Choristoneura occidentalis*

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April 1983

Potential Spotting Distance from Wind-Driven Surface Fires

Frank A. Albini

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RESEARCH SUMMARY

This paper documents a speculative model of the process by which firebrand particles are lofted into the air through the action of buoyancy-induced airflow near the head of a wind-driven fire in surface fuels. It is postulated that the particles are lofted by strong thermals generated by the fire. The fire and the thermals it generates are idealized as bein two-dimensional, for analytical tractability. It is further postulated that the fire generat the thermals because the intensity of the fire fluctuates with time in response to variations in windspeed or "gustiness." An increase in intensity above the average value, sustained for some period of time, is assumed to give birth to a line thermal with energy/length (or "strength") equal to the excess energy/length afforded by the intensity excursion. The autho has previously published theoretical power spectral densities of intensity variations of line fires in typical wildland fuels, based on a model for the dynamic response of the fire to windspeed variations and an empirical power spectrum function for horizontal wind gustiness near the surface. A simple stochastic sequence of excursions of intensity is used as a surrogate process to approximate these power spectra and so allow explicit expression of thermal strength as a function of windspeed, mean fire intensity, and fuel type. The trajectories of particles lofted by line thermals have been described elsewhere by the author Maximum viable firebrand height was shown to be proportional to the square root of the therma strength, and the downwind drift distance during lofting proportional to the product of windspeed and the square root of the loft height. The equations for predicting maximum firebrand height and drift distance during lofting are summarized here in simple form for eas field use. Once the maximum viable firebrand height is known, it can be used to predict the distance downwind that the particle will travel before it returns to the ground. Equations f this calculation have been published elsewhere, and are available as pocket calculator programs. Because several elements of the model process are both speculative and not subject to direct validation, these results are to be considered tentative. Field tests of the spotting distance predictions are sought as a means of testing the utility of the model.

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Potential Spotting Distance from Wind-Driven Surface Fires

Frank A. Albini

INTRODUCTION

The spread of wildland fire by windborne sparks or embers, known as "spotting" in the ernacular of fire control, frequently frustrates fire suppression efforts. Since there is sually no practical preventive counter to spotting, timely prediction of the maximum distance ver which spotting can be expected ahead of a fire front can be a valuable aid to tactical ire suppression planning. This paper addresses the problem of predicting the maximum spotting istance ahead of a wind-driven fire in surface fuels and presents a model for a process eading to intermediate-range spotting.

Fires burning under standing timber seldom cause spot fires at any significant distance nless the trees of the overstory become involved in the fire. This is so because the verstory crown layer affords a mechanical barrier that can intercept entrained firebrands and lso interferes with development of a strong updraft that can lift firebrand particles. But hen a tree, or a small group of trees, is ignited by the understory fire, it can burn briefly nd vigorously. This event, called "torching," produces a strong transitory convective flow hat can loft firebrand particles to significant heights. The lofting of firebrands by this echanism and their subsequent transport by the ambient windfield have been modeled (Albini 979). The model was extended (Albini 1981a) to include the lofting of firebrands by large, teady, isolated flames such as those from the burning of heavy fuel accumulations. The model nd its extensions have been coded as algorithms for pocket calculators (Chase 1981) for easy ield application.

A wind-driven fire in surface fuels without timber cover can give rise to significant potting. Generally, the greater the intensity of the fire, the more severe the spotting roblem it causes (Brown and Davis 1973; Luke and McArthur 1978). No quantitative model of the potting distance from a spreading surface fire has been developed, although much of the henomenology is widely known. The reason for this deficiency is that the fluid mechanical escription of the interaction of wind and fire is both complex and singularly difficult to pproximate with realism.

A model is presented here for intermediate-range spotting in which a spreading surface ire, idealized as a straight line perpendicular to the direction of the wind, provides the ource of buoyancy that lofts firebrand particles above the ground for transport downwind. hort-range spotting of a few tens of meters from fires of low intensity is not addressed. lso not addressed is the very long-range spotting of tens of kilometers associated with severe ire phenomena such as the establishment of fire whirls or sustained spread of fire through the rowns of timber stands. These unique phenomena require separate treatments.

Not considered in this model is the probability that there exists a firebrand particle the fuel complex that has the particular size that will permit it to be a maximum-distance fire source. Particles that are too small can be lofted to a greater height than that of t maximum-distance particle, but they will burn out before returning to the ground. Larger particles cannot be lofted so high, and thus will not travel as far. The probability of ignition by a firebrand particle is also not addressed in this paper. What is predicted is distance to which a viable firebrand could be carried. If it fails to land upon a suitable fuel to ignite, or if the fire ignited fails to spread, no spot fire will occur.

The analysis presented here consists of several steps. Each step involves idealizatio and untestable approximation of the physical realities of the situation addressed. This oblique approach stems from the need to simplify the problem in order to deal with it analytically. But in making simplifying mathematical assumptions, one always faces the possibility of discarding or badly distorting important features of the physical situation. Because it is impossible to test some key approximations of the model presented here, it is important that they be documented because they are possible sources of error. By testing t predictions of the model against experience in the field, deficiencies can be discovered. further research can trace such defects to their sources within the model so they can be corrected. A major purpose of this paper, therefore, is to leave a well-marked trail throu the analytical thicket of the model to help in finding and fixing the flaws it probably includes.

FORMULATION AND IDEALIZATION

In earlier works (Albini 1979, 1981a; Chase 1981), the trajectories of firebrand parti have been calculated, leading to formulae for spotting distance once the initial height of particle is known. These formulae can be used to predict spotting distances from wind-aide free-burning fires in surface fuels as well. What remains to be done is to predict the max height of firebrand particles lofted by such fires using observable or calculable features the behavior of the fire. As before, we consider only firebrand particles that have no aerodynamic lift (i.e., can not glide), so once the flow field of the hot plume above the f is known, the lofting flight of an entrained particle can be calculated.

Thus the problem is reduced to that of describing the aerodynamic environment above a wind-aided surface fire. To model this flow field, it is necessary to simplify the descrip of the fire, because an oblong, growing fire perimeter, with intensity a function of positi is far too complex to use as a boundary condition in the fluid flow equations. The means c simplification chosen here is to describe only the most intense segment of the fire perimet its leading edge, and to treat this segment as a straight line perpendicular to the directi of the wind.

Wildland fires seldom, if ever, have shapes that closely resemble straight lines at th leading edges. Nevertheless the front of a wind-driven surface fire frequently is nearly perpendicular to the direction of the wind over a distance that is much larger than the ext of the burning zone in the direction of the wind. Focusing on this portion of the fire, wh its intensity--as measured by the energy release rate per unit length of fire edge--is greatest, the front can be approximated as a straight line perpendicular to the direction c the wind. A mathematical idealization of this portion of the fire perimeter is that it ext indefinitely far in either direction. This is the conceptual line fire that is modeled her The intention is to model a fire that, if it did exist, would produce an aerodynamic environment for firebrand particles that would closely mimic that which exists above the leading edge of a real fire.

The mathematically ideal line fire is a two-dimensional construct that does not exist, can be closely approximated in laboratory simulations. By eliminating the third dimension the problem, analysis is greatly simplified, and models of the ideal process can be assembl

nd tested in the laboratory. This procedure has been widely followed in the field of fluid echanics dealing with buoyancy-induced flows such as from fires or other sources of heat Rouse 1947; Rankine 1950; Rouse, Yih, and Humphreys 1952; Priestly and Ball 1955; Lee and mmons 1961; Putnam 1965; Gostintsev and Sukhanov 1977, 1978; Luti 1980, 1981; lbini 1981b, 1982; Fernandez-Pello and Mao 1981) or from the discharge of buoyant fluid from a ine source (Scorer 1959; Richards 1963; Cederwall 1971; Roberts 1977, 1979a,b, 1980; Strobel nd Chen 1980). Much can be learned from the study of such idealized approximations of the eal world. If the essence of the physical process is captured, then scaling from the aboratory to the field, using mathematical modeling, can be done with confidence.

A relevant example of such scaling is the behavior of the buoyant plume from a line source n cross flow. Smoke from a heading or backing line fire in a wind is transported and dispersed by such a plume. Rankine (1950) reported experimental work done during World War II n the dispersal of fog over airport runways by a linear array of burners. The vertical and orizontal extent of the hot gas zone, as transported by a crossing wind, was to be scaled to he field situation from small indoor experiments. By dimensional analysis, he, Rouse (1947), nd Taylor (1961) deduced the importance of the ratio of the cube of the windspeed to the heat source intensity as a determining factor in fixing the angle of the buoyant flow. Byram (1959) introduced this parameter to the characterization of forest fire behavior as a measure of the bower of the wind relative to that of the fire. Putnam (1965) correlated flame tilt angle to a variable that Albini (1981b) showed to be the same as this ratio. In related research, Cederwall (1971) showed the influence of this parameter on the pattern of dispersal of buoyant effluent from a slot orifice under water. Roberts (1979a) showed experimentally that whether or not the plume from a finite-length line source in a cross flow detaches from the surface or is trapped against it depends solely on this ratio. Van Wagner (1973) used this parameter in his experimental correlation of fire intensity, windspeed, and tree crown scorch. Theoretical analysis of the buoyant plume from a line fire in wind (Gostintsev and Sukhanov 1977, 1978) showed that this ratio should have a dominant influence on plume geometry on a scale of tens of kilometers in the atmosphere. Recent numerical simulations (Luti 1980, 1981) suggest that this indeed may be so.

Using the experimental findings of Roberts (1979a), one can calculate the intensity at which a line fire should generate a plume that separates itself from the surface and rises as a distinct structure. This relationship is given in (1) and graphed in figure 1. This figure shows that fires in natural fuels should exhibit the entire range of plume behaviors, from standing to trapped against the surface in the nature of a boundary layer:

$$I = 17.5U^3 \qquad (1)$$

where I is minimum fire intensity (kW/m) and U is windspeed (m/s). Of course, this interpretation of the meaning of Roberts' experiments in terms of the behavior of fire plumes is subject to qualifications and cautions about applicability. The experiments were carried out in a free-surface water tunnel apparatus and the cross flow stream had a minimal level of turbulence. Furthermore, the velocity of the cross flow in the experiments was constant with height. All of these conditions are obviously violated by a free-burning fire. The analytical description of Gostintsev and Sukhanov (1977) showed the velocity profile with height to have a strong influence on plume geometry in the idealized two-dimensional case. So while the general behavior of a fire plume should be described qualitatively by the relationship graphed in figure 1, it should not be taken as definitive.

Armed with the prediction of figure 1, showing the general character of the flow field, one might consider modeling the mean flow structure of the plume using the integral method (Gostintsev and Sukhanov 1977, 1978). Were it not for the fact that the mean flow field should be expected to change character abruptly as the relationship between windspeed and fire intensity changes, such a model would be adequate. Because both windspeed (Davenport 1961; Doran and Powell 1982) and fire intensity (Albini 1983a) vary with time, the character of the mean flow field must be expected to alternate between plume and boundary layer types.

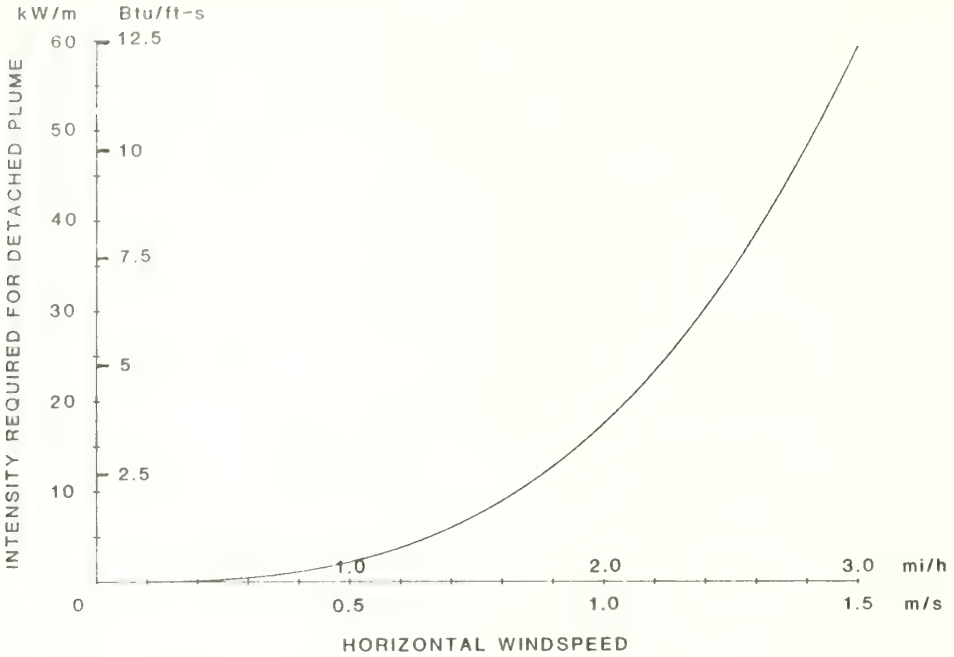

Figure 1.--Minimum fire tensity needed to pro a plume that separate from the surface as a distinct structure. range of values is re dily extended. If th windspeed is read as times the value on th horizontal axis of th graph, the intensity value read from the vertical axis is multiplied by 1,000. Re inner scales or outer scales on each axis, but do not mix them o readings will be incorrect.

TRANSPORT OF FIREBRAND PARTICLES BY THERMALS

The variation of fire intensity with time provides a mechanism for the generation of a sequence of puffs of buoyant fluid, called "thermals." This can occur as follows: When th intensity of the fire decreases to below average, as it should just after having been above average (Albini 1982), the plume tilts to an angle greater than average. This sequential alteration in the pattern of flow produces a "fold" in the plume sheet, like a wrinkle in a piece of fabric. This fold tends to pinch off and break away from the rest of the plume fl and rise as an isolated, coherent structure.

Thermals so generated are assumed in this model to provide the principal means of transporting firebrand particles. This hypothesis, crucial in the model's development, is unlikely ever to be tested directly. But if testing model predictions against experience i the field shows the predictions to be inaccurate, this assumption may be responsible.

The ability of a line thermal to transport firebrand particles has been analyzed (Albini 1983b), and the results are surprisingly simple in form. The maximum firebrand lof height was found to be roughly proportional to the square root of the energy per unit lengt (or "strength") of the thermal. Equation (2) gives this relationship :

$$H = 0.173E^{1/2} \qquad (2)$$

where H is maximum firebrand height (m) and E is thermal strength (kJ/m).

When the particle exits the rising thermal, it will be some distance downwind from the fire front where the thermal originated. This additional travel distance must be added to spotting distance predicted from the maximum firebrand height (Chase 1981). This added distance depends upon the profile of windspeed with height (Albini 1983b). If the windspeed varies as the seventh root of the height above ground (Plate 1971; Monteith 1973) then equation (3) should be used to calculate the downwind drift distance:

$$X = 2.78\ U(H)\ H^{1/2} \tag{3}$$

where X is downwind drift distance (m) and U(H) is mean windspeed (m/s) at height H, which obeys the equation

$$U(H) = U(Z)(H/Z)^{1/7}, \tag{4}$$

up to several hundred meters height (Plate 1971). Here Z is any convenient reference height (m) in the applicable range.

If the windspeed follows the logarithmic law of the wall (Monteith 1973), then equation (5) should be used:

$$X = 2.73\ U(h)\ H^{1/2}[2.13 + \ln(H/h)] \tag{5}$$

where X is downwind drift distance (m), and U(h) is mean windspeed (m/s) at vegetation cover height h (m). This form may overestimate the windspeed for small values of h, in which case (3) should be used (Albini 1981a).

With these results, the modeling problem is reduced to that of predicting the strength of the thermals generated by a line fire.

STRENGTH OF THERMALS FROM A LINE FIRE

The conceptual process for generation of thermals described above relates the variation of fire intensity with time to the generation of thermals by a wind-driven surface line fire. The variation of fire intensity with time is caused by the variations in windspeed that are always present in the near-surface atmosphere (Davenport 1961; Doran and Powell 1982). A model for the response of a line fire to nonsteady wind (Albini 1982) was used with an empirical description of the variability--or gustiness--of the wind (Davenport 1961) to derive a general picture of the variations in fire intensity to be expected in different fuels (Albini 1983a). The variations of intensity are described in terms of the power spectral density of the sequence of deviations from the mean that each fuel type should exhibit.

Figures 2-4 show the power spectral densities of fire intensity variations for twelve of the thirteen stylized fuel models (Albini 1976) used for predicting wildfire behavior (Rothermel 1983). These figures were calculated as in Albini (1983a). The fuel types shown are those that are either ordinarily found without timber cover or are used to represent such. The model for closed timber litter (fuel model 8) has been omitted, but the model for hardwood litter (model 9) is included with the grass types in figure 2, since it is often used when the deciduous overstory is bare of leaves. The timber litter and understory type (model 10) is sometimes used to represent timber harvest debris that has become overgrown with shrubs or other surface vegetation, so it is included with the logging slash fuel models in figure 3. The shrub fuel types are grouped together in figure 4. In each of these figures, the windspeed is shown in the upper righthand corner of each panel. This windspeed is the mean--long term average--value of the horizontal windspeed measured at the international anemometer standard height of ten meters above the ground.

These figures illustrate that there is very little total frequency range to the variations in fire intensity for any of the fuel models. The grass types (and hardwood litter) show variations at higher frequencies than do the slash or shrub fuels, and the frequency range tends to increase slightly as the windspeed increases. But in all cases, most of the energy in these spectra is concentrated in a single, narrow frequency-range hump at the low frequency end of the spectrum.

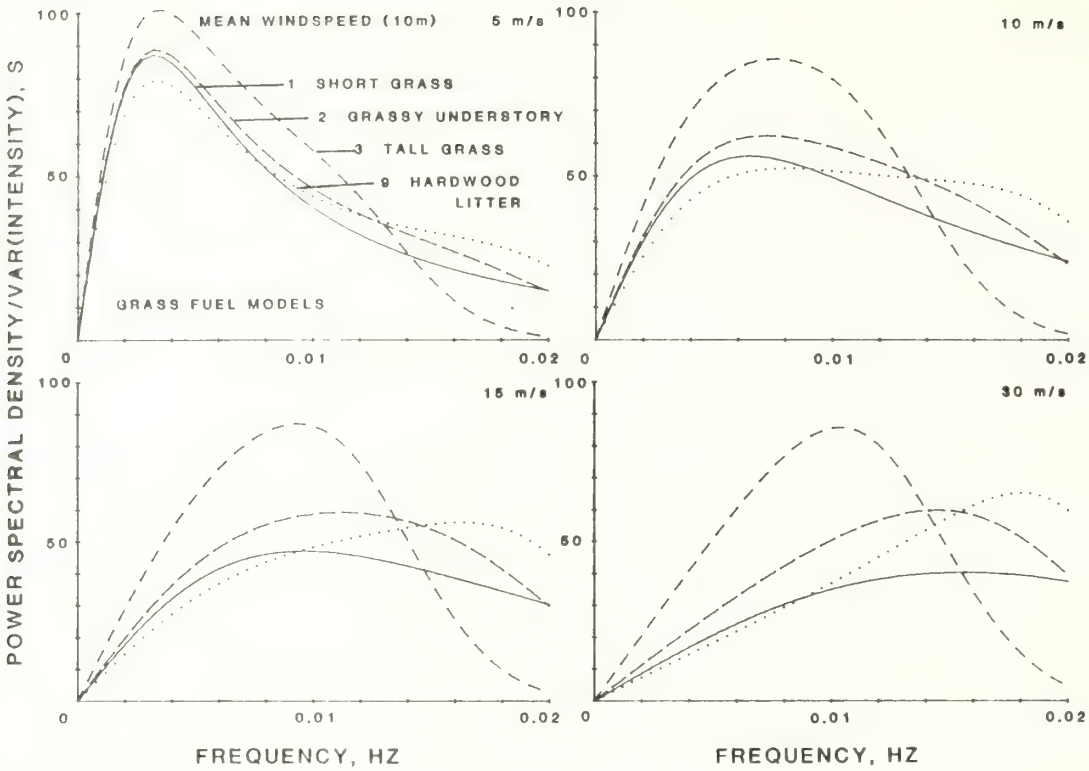

Figure 2.--Power spectral densities of fire intensity variations (divided by variance of intensity) for grass and hardwood litter fuels.

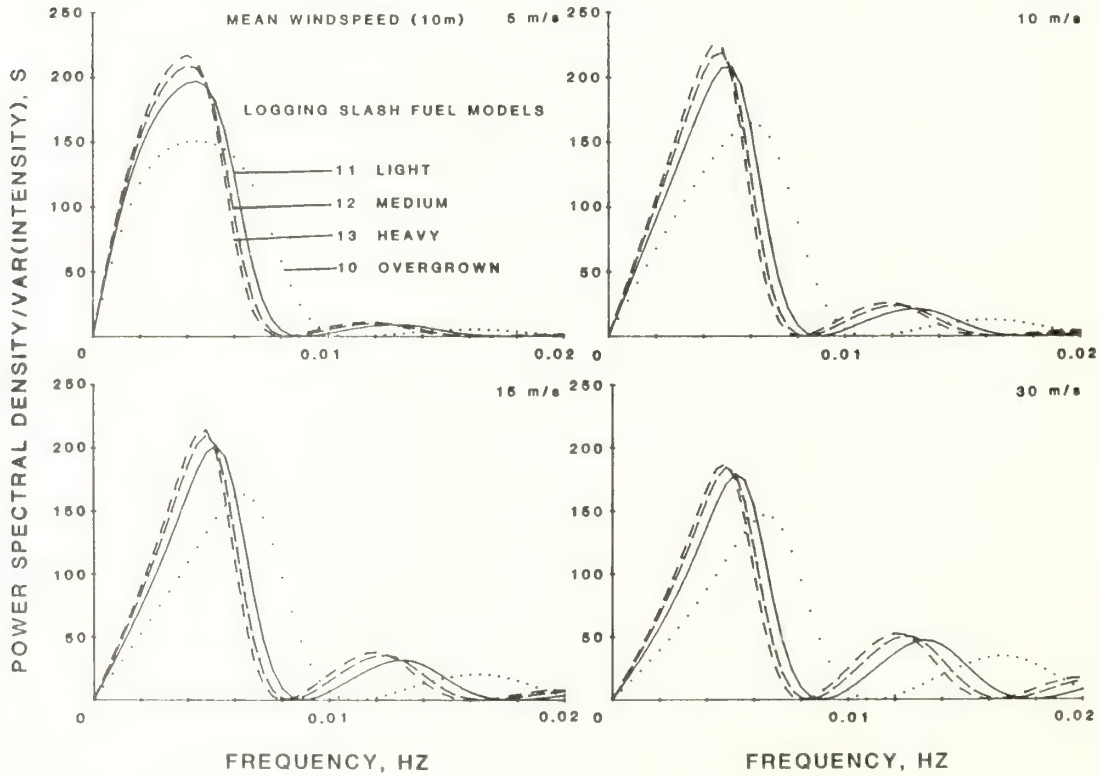

Figure 3.--Power spectral densities of fire intensity variations (divided by variance of intensity) for logging slash fuels.

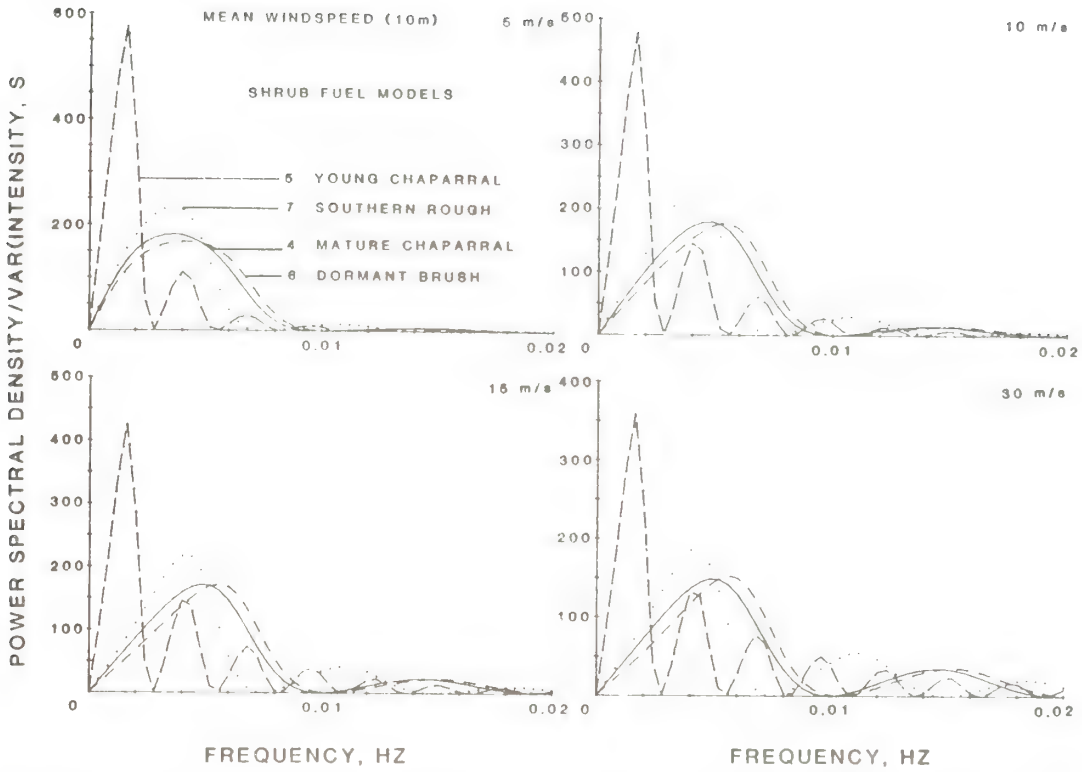

Figure 4.--Power spectral densities of fire intensity variations (divided by variance of intensity) for shrub-type fuels.

Thus much of the information contained in these spectra can be captured in two numbers: (1) the frequency at which the first (lowest frequency) maximum occurs, and (2) the maximum value of the power spectral density. Table 1 lists the frequencies of the first maxima of the power spectra of intensity variations for the twelve fuel models graphed, for windspeeds from 5 to 30 m/s. Table 2 lists the maximum values of the power spectra (normalized by the variance of fire intensity) for the same set of fuel types and windspeeds. These tables can be used as a guide and for numerical data in seeking an approximation to the pattern of fire intensity variations with time.

Such an approximation is necessary because the power spectral density alone does not contain enough information about the variation of intensity with time to reconstruct it (Bendat and Piersol 1966). To predict the strength of a thermal generated by a fluctuation in the intensity level, one needs at least the amplitude of the deviation of intensity from the mean and the duration of the excursion. The extra energy in this excursion could be concentrated in a thermal. The waveform or exact trace of the intensity-vs-time pattern is not important; rather it is the area under such a curve that measures the energy in the deviation. Thus any shape function will suffice, so long as it has the same excess energy in the deviations.

Note that the process for the formation of thermals represents another untestable but very important component of this model. It may be that the thermals shed by a line fire provide the main mechanism of firebrand transport, but that the process by which they are generated is different from that just described. If so, another model for this aspect of the process may be required. Here we assume that it is the low frequency, relatively small amplitude fluctuations of fire intensity that produce the thermals in which we are interested. Another possibility is that relatively rare but more extreme excursions cause them. These kinds of excursions should probably be analyzed as specific events, perhaps using the fire response model (Albini 1982) directly.

The model on which these graphs and tables are based predicts that modest deviations of the intensity from the mean value are most likely to occur as pairs of opposite sign and abo equal duration. That is, an increase in intensity will cause the fire spread rate to decrea leading to a subsequent proportionate decrease in intensity. The duration of the excursions should also be about equal, being fixed by the time it takes the flame front to spread vertically through the fuelbed from top to bottom. It does not matter whether an increase o decrease occurs first; the same generalization about the behavior obtains.

Table 1. *Frequencies of first maxima of fire intensity power spectra for fuel models without timber cover. Entries are in millihertz.*

Fuel models	Mean horizontal windspeed at 10 m ht, m/s					
	5	10	15	20	25	30
Grass and litter						
1 Short grass	3.2	6.5	9.5	12.1	14.0	15.5
2 Grassy understory	3.4	7.2	11.2	13.0	14.0	14.4
3 Tall grass	3.4	7.6	9.2	9.8	10.2	10.4
9 Hardwood litter	3.4	8.0	16.2	17.2	17.8	18.0
Shrub types						
4 Mature chaparral	3.6	4.6	5.0	5.0	5.0	5.0
5 Young chaparral	1.6	1.6	1.6	1.6	1.6	1.6
6 Dormant brush	4.0	5.4	5.6	5.6	5.6	5.6
7 Southern rough	3.6	4.0	4.2	4.2	4.2	4.2
Logging slash						
10 Overgrown slash	4.4	6.0	6.4	6.4	6.4	6.4
11 Light conifer slash	4.4	5.0	5.2	5.2	5.2	5.2
12 Medium conifer slash	4.0	4.6	4.8	4.8	4.8	4.8
13 Heavy conifer slash	4.0	4.6	4.6	4.8	4.8	4.8

Table 2. *Value of power spectral density/variance at first maximum for fuel models without timber cover. Entries are in seconds.*

Fuel models	Mean horizontal windspeed at 10 m ht, m/s					
	5	10	15	20	25	30
Grass and litter						
1 Short grass	87.0	56.0	47.1	43.5	41.5	40.3
2 Grassy understory	88.7	62.2	59.2	59.7	60.1	59.8
3 Tall grass	100.9	85.6	87.0	87.3	86.8	85.8
9 Hardwood litter	79.2	52.2	56.0	60.8	63.6	65.2
Shrub types						
4 Mature chaparral	182	180	172	162	156	149
5 Young chaparral	576	478	430	393	375	358
6 Dormant brush	168	177	172	165	158	152
7 Southern rough	234	234	219	206	195	187
Logging slash						
10 Overgrown slash	151	165	164	158	152	147
11 Light conifer slash	195	209	202	193	186	179
12 Medium conifer slash	209	220	210	200	192	185
13 Heavy conifer slash	217	226	215	204	195	188

Based on this understanding of the phenomenology, and guided by the fact that only the energy in a deviation of the intensity from the mean for a short time is required to calculate the strength of a thermal, a surrogate process of time-dependent fire intensity is fabricated and analyzed to provide a link between mean fire intensity and the strength of generated thermals. The process invented for analysis consists of a series of deviations from the mean, each being of the same amplitude and each lasting for the same time, but occurring at random intervals of time with a constant long-term average rate. One of these excursions consists of a sudden change in fire intensity from the mean value, followed a short time later by a sudden change of equal magnitude but of the opposite sign, which lasts for the same time. The average value of such an excursion is zero, since it has the same deficit in intensity as it has excess, and the deviations are each of the same duration. Mathematically, one describes such an event as a one-period square wave. The power spectral density of such a sequence of brief oscillations is derived in appendix A.

Figure 5 shows a set of power spectra from the process analyzed. The only parameters needed to describe the sequence are the period--or total duration--of an event, the magnitude of the increase and decrease, and the mean rate of occurrence of the events. The mean rate of occurrence, multiplied by the event period, gives the probability that such an event will be occurring at any arbitrarily selected time of observation. This probability (identified as P_{ON}) is used as a parameter in figure 5, to specify the different curves. The event period is used to multiply the frequency, giving the dimensionless x-axis variable of the graphs. By dividing the power spectral density by the product of the probability parameter, the square of the deviation amplitude, and the event period, the y-axis variable is also made dimensionless.

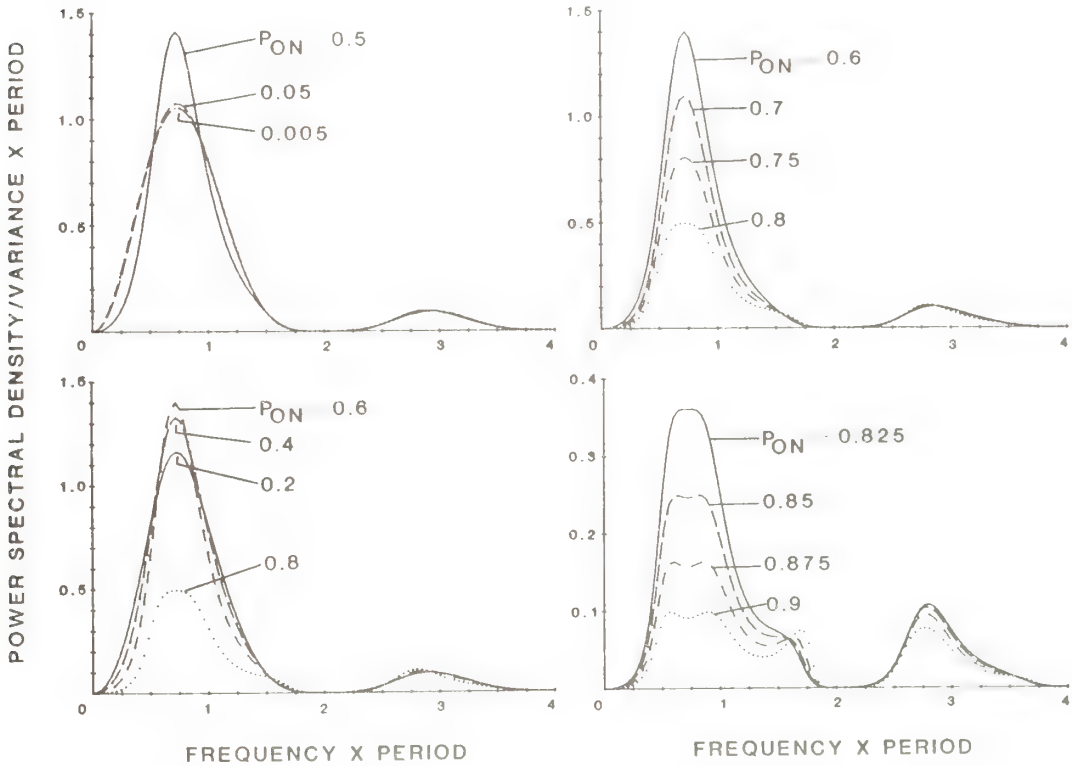

Figure 5.--Power spectral density (divided by product of event period and variance of amplitude) of an ergodic sequence of one-period square wave events with random occurrences. The parameter P_{ON} is the a priori probability that an event is ongoing at any arbitrary point in time. The variance is thus P_{ON} times the mean of the square of the amplitude of the deviations.

The product of the probability and the square of the amplitude is also the variance of intensity. Thus to match these curves with those given by the modeled fire intensity power spectra in figures 2-4, one need only match the peak of the power spectral density and the frequency at which it occurs. This entails picking a probability value and selecting the event period for the surrogate process. Figure 6 shows examples of the matches that are achieved using this technique.

The graphs in figure 6 illustrate that the match between the hypothetical pattern of intensity variations and that predicted for "real" fires is not very good for the grass and hardwood litter fuels at low windspeed. The surrogate process exaggerates the contribution the lower frequencies and underestimates the contribution from higher frequencies. The mode therefore would tend to overestimate the strengths of the thermals generated, by concentrati too much energy in the intensity deviations assumed. A more realistic waveform would contai more high-frequency components and so reduce the energy in these "square wave thermals". Th match to the general shape of the spectra becomes better at higher windspeeds for these fuel For the slash and shrub fuel types, the match of shapes of the spectra is generally good, at least qualitatively, over the entire range of windspeeds. Again, the errors implied by the nature of the mismatches are such as to overestimate the strengths of the thermals.

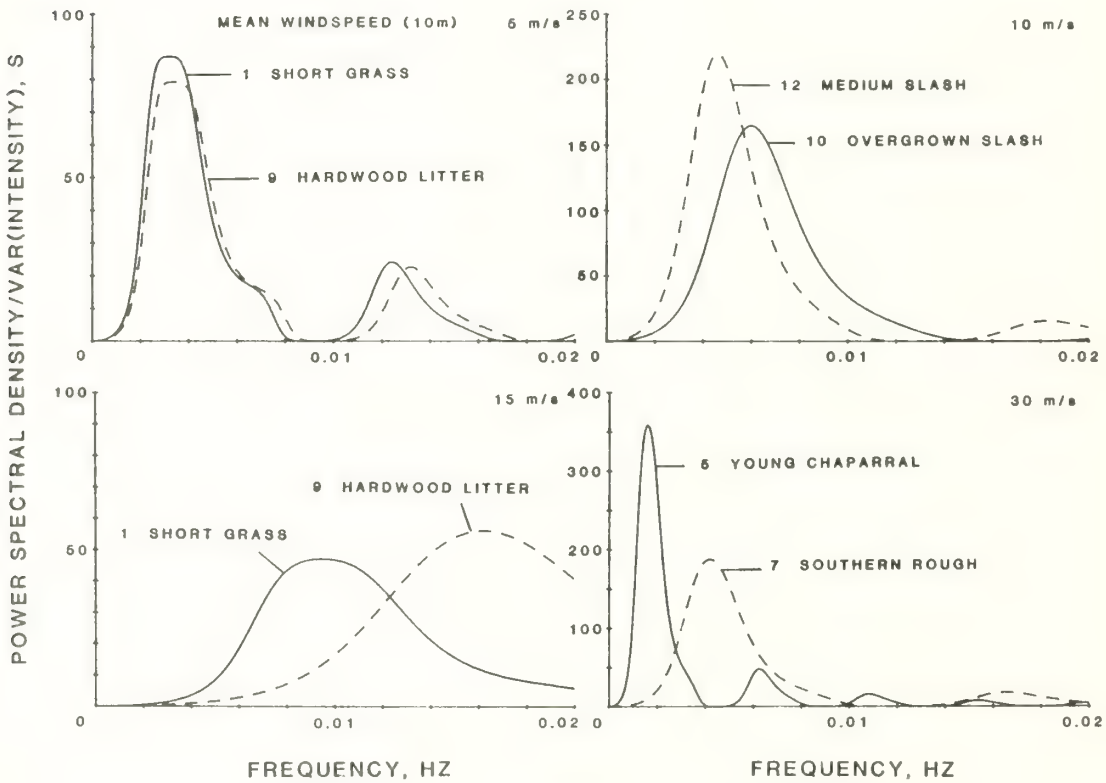

Figure 6.--Results of equating the peak of the power spectral density and the frequency at which it occurs, using the hypothetical spectral density formula derived in appendix A (as graphed in fig. 5) and the predicted power spectral densities for the various fuel models as graphed in figures 2-4. Compare these graphs with the ones they are intended to approximate in figures 2-4.

With the substitution of the hypothetical process for the actual but unknown fire intensity variation pattern, the energy in a thermal becomes very easy to calculate. It is simply the product of the magnitude of the intensity variation multiplied by half the event period. The period is determined by matching the frequencies of the peaks of the power spectra, and the magnitude of the deviations is determined by matching the peak values of the power spectra. The resulting expression for the energy in a thermal becomes a numerical constant multiplied by the standard deviation of the fire intensity variations and divided by the frequency of the peak in the power spectrum. This form could have been predicted at the outset purely from dimensional arguments. The numerical values of the constants are the only quantities that depend upon the specific model chosen as a surrogate for the real variations in fire intensity. For that reason, the details of this substituted process are of no great consequence to the predictions of this model.

The value of the standard deviation of fire intensity, expressed as a percentage of the mean fire intensity, is presented for the 12 fuel models analyzed in table 3. These results are predicted directly by the intensity fluctuation model (Albini 1983a) and do not depend at all on the substitute process. Note that the fractions in table 3 decline with increasing windspeed. This does not mean that the strength of the thermals decreases with windspeed. On the contrary, because the mean fire intensity increases with windspeed faster than the percentage deviations decrease, and the periodicity remains about constant, the thermals in fact become stronger.

Table 3. *Values of the standard deviation of fire intensity, as a percentage of the mean intensity (coefficient of variation) for 12 fuel models that occur without timber cover.*

Fuel model	Mean horizontal windspeed at 10 m ht, m/s					
	5	10	15	20	25	30
Grass and litter						
1 Short grass	12.5	9.30	7.36	6.01	5.03	4.28
2 Grassy understory	18.8	15.2	12.5	10.4	8.79	7.54
3 Tall grass	16.4	12.0	9.09	7.12	5.74	4.75
9 Hardwood litter	23.5	21.2	18.9	16.7	14.9	13.3
Shrub types						
4 Mature chaparral	13.3	8.27	5.76	4.34	3.43	2.82
5 Young chaparral	8.11	4.70	3.33	2.59	2.11	1.79
6 Dormant brush	16.2	11.0	8.06	6.28	5.10	4.28
7 Southern rough	14.4	9.19	6.63	5.14	4.18	3.51
Logging slash						
10 Overgrown slash	18.3	13.3	10.2	8.19	6.84	5.87
11 Light conifer slash	17.1	11.8	8.87	7.07	5.86	5.01
12 Medium conifer slash	16.3	11.0	8.13	6.43	5.30	4.50
13 Heavy conifer slash	16.0	10.7	7.92	6.26	5.16	4.38

The final step in this lengthy process is to relate the strengths of the thermals to th mean fire intensity and windspeed for each fuel model:

$$E = I\ f(U) \tag{7}$$

where E is the strength of a thermal (kJ/m), I is mean fire intensity (kW/m), and f(U) is a function of the mean windspeed at 10 m height. This function was found by fitting a power l of the form:

$$f(U) = A\ U^{B} \tag{8}$$

(f in units of seconds) to the numerical results obtained for each of the 6 windspeeds used the tables above. By this process, the simple final results given in table 4 were derived.

Table 4. *Results of power law regressions to approximate the energy in line thermals generated by burning various fuels. E/I = A exp (B log U) where E is the energy in a thermal and I is mean fire intensity. Units of coefficient A are in seconds and U is 10-m height mean windspeed, m/s.*

Fuel model	A (s)	B	Coefficient of determination
Grass and litter			
1 Short grass	162	-1.456	1.000
2 Grassy understory	166	-1.282	.998
3 Tall grass	129	-1.238	.996
9 Hardwood litter	154	-1.151	.979
Shrub types			
4 Mature chaparral	83.9	-1.040	1.000
5 Young chaparral	94.4	- .881	1.000
6 Dormant brush	74.1	- .906	1.000
7 Southern rough	75.1	- .884	.998
Logging slash			
10 Overgrown slash	66.1	- .810	.998
11 Light conifer slash	63.6	- .776	.993
12 Medium conifer slash	69.6	- .818	.997
13 Heavy conifer slash	71.8	- .835	.995

SPOTTING DISTANCE EXAMPLES

To illustrate the use of the formulation presented here, two examples are computed. In the first example, we estimate the maximum spotting distance from a wind-driven fire in short grass; in the second example the fuel is chaparral, and we consider a higher windspeed. For simplicity, the terrain is considered to be flat in both cases.

Example 1. Estimate the maximum spot fire distance from a heading fire in short grass, with intensity of 2000 kW/m (580 Btu/ft-s) when the mean windspeed at 10-m height is 5 m/s (about 11 mi/h).

We must use equation (7) to find the energy (E) in a thermal from the line fire. We have the intensity (I), so we refer to table 4 to find the parameters defining the multiplying function f(U). Table 4 gives, for short grass, A = 162, B = -1.465. The windspeed (U) is 5 m/s, so the multiplying function f(U) is given by

$$f(U) = A\,U^{B} = 162 \times (5)^{-1.465} = 15.33 \text{ s}. \qquad (9)$$

Multiplying this factor by the intensity (I = 2000 kW/m) gives the thermal energy:

$$E = I\,f(U) = (2000) \times (15.33) = 30\,660 \text{ kJ/m}. \qquad (10)$$

This energy is used in equation (2) to obtain the maximum firebrand particle height, H:

$$H = 0.173\,E^{1/2} = 0.173 \times (30\,660)^{1/2} = 30 \text{ m}. \qquad (11)$$

This quantity is the initial firebrand particle height. Using the formulae in Chase (1981), where this height is called z(0), we find that the cover height associated with short grass is too low to allow use of the logarithmic windspeed profile, and that we must use instead an "effective cover height" (Albini 1981a) of 1.93 m to calculate the maximum spotting distance. Using the formula in Chase (1981), p. 5, for the flat-terrain spotting distance, there labeled F, we discover that we require the windspeed (in km/h) at 6 m height. We can obtain this from equation (4), using the power law profile for windspeed with height. We use this profile because it is convenient and closely approximates the logarithmic law, although either could be used without introducing error beyond that probably inherent in the model.

Using equation (4), we estimate the windspeed at 6 m height to be:

$$U(6\text{m}) = U(10\text{m}) \times (6/10)^{1/7} = 0.93 \times U(10\text{m})$$

$$= 0.93 \times 5 = 4.65 \text{ m/s} = 16.7 \text{ km/h}. \qquad (12)$$

This windspeed can be used in the equation in Chase (1981) to calculate the maximum spotting distance, with the result:

$$F = \text{flat terrain spotting distance} = 0.17 \text{ km}. \qquad (13)$$

To this distance it is necessary to add the downwind drift during lofting, from equation (3). That equation requires the windspeed at the maximum particle height. Again we return to equation (4) to estimate that value, with the result:

$$U(30m) = U(10m) \times (30/10)^{1/7} = 5 \times 1.17 = 5.85 \text{ m/s}. \quad (14)$$

Using this value in equation (3) gives the spotting distance correction as:

$$X = 2.78 \times 5.85 \times (30)^{1/2} = 89 \text{ m} = 0.09 \text{ km}. \quad (15)$$

This result illustrates the importance of the correction term in this instance, since th distance is about half that predicted due to falling from the initial height in the wind. Adding the correction to the original prediction (12), gives the final result of 0.26 km (or about 0.16 mi).

Example 2. Estimate the maximum spot fire distance from a wind-driven fire in chaparral when the windspeed at 10 m height is 20 m/s and the fire intensity is calculated to be 50 000 kW/m (about 14,400 Btu/ft-s).

This is a severe surface fire with very high intensity and very strong wind. Large spotting distances might be expected, especially in light of the results of the first example

Again, the first step is to estimate the strength of the thermals from the line fire. Table 4 gives the values A = 83.9 and B = -1.04. Using these in the equation for f(U)--equation (8)--gives a multiplier of

$$f(U) = A\ U^{B} = (83.9) \times (20)^{-1.04} = 3.72 \text{ s}, \quad (16)$$

and so a thermal strength, from equation (7), of

$$E = I\ f(U) = (50\ 000) \times (3.72) = 186\ 000 \text{ kJ/m}. \quad (17)$$

Using this result in equation (2) gives the maximum firebrand lofting height

$$H = 0.173\ E^{1/2} = 0.173 \times (431) = 75 \text{ m}. \quad (18)$$

As before, it is necessary to estimate the windspeed at 6 m height, and again we can use equation (4). Doing so gives the value 66.9 km/h at the lower height. Also as in the previo case, the formulation in Chase (1981) restricts us to use of the power law windspeed profile, and hence to use of an artificial cover height. With these data in hand, Chase's formula giv a flat-terrain spotting distance (F) of 1.26 km.

The downwind drift during particle lofting again is a large correction to this result. Once more using equation (4) to extrapolate the windspeed to the firebrand height, we find

$$U(75m) = U(10\ m) \times (75/10)^{1/7} = 26.7 \text{ m/s}. \quad (19)$$

This result, used in equation (3), gives the correction to be added to the predicted spotting distance:

$$X = 2.78 \times (26.7) \times (75)^{1/2} = 642 \text{ m} = 0.64 \text{ km}. \tag{20}$$

The final result in this case is 1.26 + 0.64 = 1.90 km, or about 1.2 mi. This result may seem to be a low estimate. Note, however, that even with this high intensity, equation (1) predicts that the wind field should overpower the convection column and blow the smoke along the surface. In such situations, long range spotting is infrequent.

SUMMARY

SUMMARY

The process by which firebrands are transported from wind-driven line fires is postulated to be that of lofting of particles by line thermals that are generated by variations in the intensity of the fire. Both the mechanism of firebrand lofting and the mechanism of the generation of thermals are speculative assumptions that are probably not directly subject to test. Because of this fact, the model presented here is a theoretical construct and will probably remain so, even if field tests show its predictions to be usefully accurate. The motivation for this approach is simply that the problem in its general form is analytically intractable, being both three-dimensional and time-dependent. This analysis preserves the appealing idealization of two-dimensionality, but incorporates in a weak way the time variability. The postulation of a surrogate time sequence process representing the fire intensity variations permits direct computation of the strength of thermals generated by a line fire, with little additional distortion suspected. Equations presented here permit direct computation of the maximum firebrand lofting height and the drift downwind during lofting, given the mean intensity of the fire, the mean windspeed at 10 m height, and a fuel description in terms of one of twelve stylized models widely used for predicting the behavior of wildland fires. From the maximum firebrand lofting height, the maximum spotting distance is calculable using equations and graphs available in earlier publications or published pocket calculator algorithms.

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APPENDIX A: POWER SPECTRAL DENSITY OF AN ERGODIC SEQUENCE OF ONE-PERIOD 'SQUARE WAVE' EVENTS

Process Description

A process described by a function of time that is in some sense unpredictable is said to be stochastic. Here we consider the stochastic process described by the function x(t), where is time,

$$x(t) = x_o + \sum_{i=-\infty}^{+\infty} W(t - t_i) \tag{1}$$

x_o is the mean or long-term average of x, the times t_i are random, and W is a "square wave" of amplitude A and period T:

$$W(t') = \begin{cases} 0 & t' \leq 0 \\ A & 0 < t' < T/2 \\ 0 & t' = T/2 \\ -A & T/2 < t' < T \\ 0 & t' \geq T. \end{cases} \tag{2}$$

It is further stipulated that the times t_i are sufficiently separated that the waveforms of the various one period deviations of x(t) from x_o do not overlap:

$$|t_i - t_j| \geq T;\ i \neq j. \tag{3}$$

The realization of x(t) expressed by (1)-(3) can be visualized as a sequence of events which occur at random times. An "event" is the deviation of x(t) from its mean value, x_o. As time goes on, these events recur; but while an event is ongoing ($t_i < t < t_i + T$), another event cannot occur. For simplicity, we assume here that the amplitude, A, and duration, T, of each event is the same. These restrictions can be relaxed later if necessary.

A more powerful constraint that we shall not relax is the assumption that the process is ergodic. For the process under discussion, this can be stated as a requirement that the time elapsed between sequential events can be described as a random variable, whose distribution function is independent of time. This simple requirement ensures that the statistical properties of any finite sample of the function x(t) do not depend *a priori* upon when the sample is taken. Therefore an ensemble of such finite samples can be substituted, conceptually, for a single time stream sample of the same total duration. The equivalence of ensemble-averaged and time-averaged statistics is of enormous analytical consequence.

Specifically, let f(θ) be the probability density function for the distribution of times (θ) that elapse between the end of one event and the beginning of the next. If f(θ) does not depend upon t, then the process described will be ergodic. For example, with a large enough sample, the average time lapse between events, T_L, will approach the mean of the distribution f(θ):

$$T_L \rightarrow \int_0^{\infty} \theta f(\theta) d\theta. \tag{4}$$

utocorrelation Function

A characterization of the process x(t) in terms of its frequency content is expressed by ts power spectral density, $S_x(n)$, where n is frequency. The most direct approach to erivation of S_x is through use of the autocorrelation function of the process, $C_x(\tau)$:

$$C_x(\tau) = \lim_{t \to \infty} \frac{1}{t} \int_{-t/2}^{+t/2} x(t')x(t' + \tau)dt'. \tag{5}$$

ecause we are dealing with a mathematically real process, C_x is an even function of τ and he power spectrum can be written as the cosine transform of C_x (Bendat and Piersol, 1966):

$$S_x(n) = 4\int_0^\infty \cos(2\pi n\tau)C_x(\tau)d\tau. \tag{6}$$

Without loss of generality, the mean, x_o, can be taken to be zero. Then $C_x(0)$ becomes he variance of the process and a singularity at n = 0 is removed from $S_x(n)$.

Making use of the ergodic property of the process, the time averaging operation of (5) can e replaced by an ensemble average, expressed here as the expectation operator E:

$$C_x(\tau) = E(x(t)x(t + \tau)). \tag{7}$$

The expected value of the product $x(t)x(t + \tau)$ can be deduced (conceptually) by sampling the value of the product uniformly over a large ensemble of records of the function x(t). The product clearly can take on only three values, namely A^2, $-A^2$, and 0. The task at hand is to describe, as a function of τ, the fraction of the samples that would have each of these values, given the distribution function for the time lapse between events, $f(\theta)$.

Consider first the value of x(t). It will be nonzero only a fraction of the time (or for only a fraction of the number of samples, for any given time on the record of each sample). This fraction can be interpreted as P_{ON}, the *a priori* probability that an event will be ongoing at any arbitrarily selected time during a sample record. If we consider a long-duration record with a total time span T*, then the number of events that we should expect to observe during that time is N*, where the total time during which events are occurring can be expressed as

$$N^*T = P_{ON}T^*. \tag{8}$$

But the average time elapsed between events is T_L (Eq. 4), so the total timespan should also be expressable as

$$T^* = N^*(T_L + T). \tag{9}$$

Hence the probability that an event is ongoing at any arbitrary time is

$$P_{ON} = T/(T_L + T), \tag{10}$$

and the mean rate of occurrence of events, ν, is

$$\nu = N^*/T^* = 1/(T_L + T) = P_{ON}/T. \tag{11}$$

We can now express (7) in terms of a conditional expectation $\gamma(\tau)$, where

$$\gamma(\tau) = E(x(t)x(t + \tau)|x(t) \neq 0), \tag{12}$$

by which we mean the expected value of $x(t)x(t + \tau)$, given that $x(t)$ is not zero. Depending upon τ, the product can still vanish because the second factor may be zero, but in general

$$C_x(\tau) = P_{ON}\gamma(\tau). \tag{13}$$

Because $\gamma(0)$ is A^2, we can normalize (13) by the variance of the process and deal with the normalized conditional autocorrelation function, G:

$$C_x(\tau)/\sigma^2 = C_x(\tau)/P_{ON}A^2 = \gamma(\tau)/A^2 = G(\tau). \tag{14}$$

To express $G(\tau)$ explicitly, it is necessary to introduce the additional conditional probability function, $P(\theta)$. This function represents the distribution of probability that a event starts at time θ after the cessation of a given event, whether or not one or more intervening events. Specifically,

$$\Pr\left\{\begin{matrix}\text{an event starts at time } (\theta,\theta+d\theta) \\ \text{after a given event ceases}\end{matrix}\right\} = P(\theta)d\theta. \tag{15}$$

This function can be defined by the recursion:

$$P(\theta) = \begin{cases} f(\theta), & \theta < T \\ f(\theta) + \displaystyle\int_0^{\theta-T} f(x)P(\theta - T - x)dx, & \theta \geq T . \end{cases} \tag{16}$$

Recall that $f(\theta)$ represents the probability distribution function for the beginning of the n event after the one whose cessation marks the origin of relative time, θ. The integral in (can be evaluated for $2T > \theta \geq T$ by using f for P in accordance with (16), and extended by recursively applying the same algorithm. Note that no closure condition applies to the conditional distribution P. It does apply to f, however, which means that the asymptotic solution to (16) is a constant. P must become independent of the time origin for large θ and indeed should approach the mean rate of occurrence, ν (Eq. 11):

$$\lim_{\theta \to \infty} P(\theta) = \nu. \tag{17}$$

The function P will obviously be complicated if written explicitly, but its use symbolically allows compact notation for the correlation function G.

To express G explicitly, we can imagine examining the statistics of the product x(t)x(t formed from a large sample of such, all satisfying the stipulation that $x(t) \neq 0$. This is equivalent to placing a relative time origin somewhere within the period of one event with uniform probability, noting the value of x at that point, and forming its product with the expected value of x at a time τ later. This conceptual artifice allows us to write the following expressions by inspection:

$$\underline{0 \le \tau \le T/2:} \quad G(\tau) = \int_0^{T/2-\tau} \frac{dt}{T} - \int_{T/2-\tau}^{T/2} \frac{dt}{T} + \int_{T/2}^{T-\tau} \frac{dt}{T} - \int_{T-\tau}^{T} \int_0^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} \tag{18}$$

$$\underline{T/2 \le \tau \le T:} \quad G(\tau) = -\int_0^{T-\tau} \frac{dt}{T} + \int_{T-\tau}^{T/2} \int_0^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} - \int_{T/2}^{T} \int_{\max(0,t+\tau-3T/2)}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T}$$

$$+ \int_{3T/2-\tau}^{T} \int_0^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T} \tag{19}$$

$$\underline{T \le \tau \le 3T/2:} \quad G(\tau) = \int_0^{T/2} \int_{\max(0,t+\tau-3T/2)}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} + \int_{T/2}^{T} \int_{\max(0,t+\tau-2T)}^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T}$$

$$- \int_{3T/2-\tau}^{T/2} \int_0^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T} - \int_{T/2}^{T} \int_{t+\tau-3T/2}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} \tag{20}$$

$$\underline{3T/2 \le \tau \le 2T:} \quad G(\tau) = \int_0^{T/2} \int_{t+\tau-3T/2}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} + \int_{T/2}^{T} \int_{t+\tau-2T}^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T}$$

$$- \int_0^{T/2} \int_{\max(0,t+\tau-2T)}^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T} - \int_{T/2}^{T} \int_{t+\tau-3T/2}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} \tag{21}$$

$$\underline{2T \le \tau:} \quad G(\tau) = \int_0^{T/2} \int_{t+\tau-3T/2}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} + \int_{T/2}^{T} \int_{t+\tau-2T}^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T}$$

$$- \int_0^{T/2} \int_{t+\tau-2T}^{t+\tau-3T/2} P(\theta)d\theta \, \frac{dt}{T} - \int_{T/2}^{T} \int_{t+\tau-3T/2}^{t+\tau-T} P(\theta)d\theta \, \frac{dt}{T} \, . \tag{22}$$

These expressions can be simplified somewhat, but first note that by integrating (6) twice by parts and using (14), we have, for a suitably continuous and differentiable $G(\tau)$:

$$\frac{(\pi n)^2 S_x(n)}{P_{0N} A^2} = -G'(0) - \int_0^{\infty} \cos(2\pi n\tau) G''(\tau) d\tau \tag{23}$$

where the number of prime signs indicates the number of differentiations with respect to the argument.

Power Spectral Density

Integration by parts and simplification before differentiating helps in deriving the second derivative form needed for evaluating (23). Note from (22), however, that $G(\tau)$ vanishes for large τ if P becomes constant, and $G''(\tau)$ must also vanish. Performing the indicated operations gives the piecewise continuous functionals G' and G'':

$0 \le \tau \le T/2$:

$$G'(\tau) = -3/T - \int_0^{\tau} P(\theta)d\theta/T \tag{24}$$

$T/2 \le \tau \le T$:

$$G'(\tau) = 1/T + (3/T)\int_0^{\tau-T/2} P(\theta)d\theta - \int_{\tau-T/2}^{\tau} P(\theta)d\theta/T \tag{25}$$

$T \le \tau \le 3T/2$:

$$G'(\tau) = (3/T)\left\{\int_{\tau-T}^{\tau-T/2} P(\theta)d\theta - \int_0^{\tau-T} P(\theta)d\theta\right\} - \int_{\tau-T/2}^{\tau} P(\theta)d\theta/T \tag{26}$$

$3T/2 \le \tau \le 2T$:

$$G'(\tau) = (3/T)\left\{\int_{\tau-T}^{\tau-T/2} P(\theta)d\theta - \int_{\tau-3T/2}^{\tau-T} P(\theta)d\theta\right\} + (1/T)\left\{\int_0^{\tau-3T/2} P(\theta)d\theta - \int_{\tau-T/2}^{\tau} P(\theta)d\theta\right\} \tag{27}$$

$2T \le \tau$:

$$G'(\tau) = (1/T)\left\{\int_{t-T/2}^{t-3T/2} P(\theta)d\theta - \int_{\tau-T/2}^{\tau} P(\theta)d\theta\right\} + (3/T)\left\{\int_{\tau-T}^{\tau-T/2} P(\theta)d\theta - \int_{\tau-3T/2}^{\tau-T} P(\theta)d\theta\right\} \tag{28}$$

$0 \le \tau \le T/2$:

$$G''(\tau) = -P(\tau)/T \tag{29}$$

$T/2 \le \tau \le T$:

$$G''(\tau) = -P(\tau)/T + (4/T)P(\tau - T/2) \tag{30}$$

$T \le \tau \le 3T/2$:

$$G''(\tau) = -P(\tau)/T + (4/T)P(\tau - T/2) - (6/T)P(\tau - T) \tag{31}$$

$3T/2 \le \tau \le 2T$:

$$G''(\tau) = -P(\tau)/T + (4/T)P(\tau - T/2) - (6/T)P(\tau - T) + (4/T)P(\tau - 3T/2) \tag{32}$$

$2T \le \tau$:

$$G''(\tau) = -P(\tau)/T + (4/T)P(\tau - T/2) - (6/T)P(\tau - T) + (4/T)P(\tau - 3T/2) - (1/T)P(\tau - 2T). \tag{33}$$

Now because $G'(\tau)$ is discontinuous, the simple form of (23) cannot be used directly. It is necessary instead to evaluate the contributions of each of the discontinuous segments due t the differences in the value of G' as approached from opposite directions at each matching point.

The appearance of the functions of shifted arguments in each of the above expressions coincides with the breaks in applicability of the expressions, leading to a particularly simpl form (using circular frequency ω for $2\pi n$) for the contribution of G'' to the power spectrum:

$$-\int_0^{\infty} \cos(\omega\tau)G''(\tau)d\tau = \int_0^{\infty} P(\tau)\Gamma(\tau)d\tau/T. \tag{34}$$

Here

$$\Gamma(\tau) = \cos(\omega\tau)-4\cos(\omega\tau+\omega T/2)+6\cos(\omega\tau+\omega T)-4\cos(\omega\tau+3\omega T/2)+\cos(\omega\tau+2\omega T), \tag{35}$$

which can be shown to be

$$\Gamma(\tau) = 16\sin^4(\omega T/4)\cos(\omega\tau + \omega T). \tag{36}$$

The contributions to (23) of the discontinuities of $G'(\tau)$ consist of a sum of terms of the form

$$\cos(k\omega T/2)[G'_+(kT/2) - G'_-(kT/2)] \tag{37}$$

where k = 1,2,3, or 4 and the subscript sign implies the direction of approach to the discontinuity. Thus to (23) we must add the following sum, due to the differences between the limits of (24) and (25) and (25) and (26):

$$-(4/T)\cos(\omega T/2) + (1/T)\cos(\omega T).$$

Thus we have the relatively simple form for the power spectrum:

$$\begin{aligned}\frac{\omega^2 T\, S_x(n)}{4P_{ON}A^2} &= 3 - 4\cos(\omega T/2) + \cos(\omega T) \\ &\quad + 16\sin^4\left(\frac{\omega T}{4}\right)\int_0^\infty \cos(\omega\tau+\omega T)P(\tau)d\tau \\ &= 8\sin^4\left(\frac{\omega T}{4}\right)\left\{1 + 2\int_0^\infty P(\tau)\cos(\omega\tau+\omega T)d\tau\right\}.\end{aligned} \tag{38}$$

Uniform Occurrence Rate Probabilities

The simple form of (38) rests upon the hidden complexity of the ubiquitous conditional probability function $P(\theta)$. This function is determined by the probability density function for the occurrence of the next subsequent event, $f(\theta)$, as expressed in (16). To express $f(\theta)$ and $P(\theta)$ analytically, we invoke this assumption:

> Given the condition that an event is not ongoing, the probability that an event begins in the next differential element of time, dt, is μdt, where μ is constant.

This assumption is very widely used in the mathematical analysis of queueing processes (Saaty 1959) and, in the limit of zero event duration, leads to a Poisson distribution for the number of events in a finite time.

Using this assumption, one readily can show that the probability density $f(\theta)$ for the occurrence of the next subsequent event is

$$f(\theta) = \mu\exp(-\mu\theta). \tag{39}$$

The mean time lapse between events (eq. 4) is thus $1/\mu$, and the longterm probability that an event is ongoing at any arbitrary time (eq. 10) is

$$P_{ON} = \mu T/(1 + \mu T). \tag{40}$$

Thus the longterm mean rate of occurrence of events (eq. 11) is

$$\nu = \mu/(1 + \mu T). \tag{41}$$

By introducing (39) into (16) and carrying out the indicated operations, one finds

$$P(0 \leq \theta \leq T) = \mu\exp(-\mu\theta) \tag{42}$$

$$P(T \leq \theta \leq 2T) = \mu\exp(-\mu\theta) + \mu^2(\theta-T)\exp(-\mu(\theta-T)) \tag{43}$$

$$P(2T \leq \theta \leq 3T) = \mu\exp(-\mu\theta) + \mu^2(\theta-T)\exp(-\mu(\theta-T)) + (\mu^3(\theta-2T)/2)\exp(-\mu(\theta-2T)). \tag{44}$$

The apparent generalization of this sequence,

$$P(\theta) = \mu\sum_{k=0}^{[\theta/T]}((\mu(\theta-kT))^k/k!)\exp(-\mu(\theta-kT)), \tag{45}$$

can be proved by induction using eq. (16). This form can be thought of as a generalization of the Poisson process wherein $P(\theta) = \mu$ everywhere. Indeed, when the events have vanishing duration, we retrieve the obvious result

$$\lim_{T\to 0} P(\theta) = \mu. \tag{46}$$

The limit of (45) as θ increases without bound is already known by prior reasoning (eq. 17) to be

$$\lim_{\theta\to\infty} P(\theta) = \nu = (1 - P_{ON})\mu = \mu/(1 + \mu T), \tag{47}$$

but it is difficult to derive this analytically. Straightforward numerical evaluation of (45) however, confirms that this limit obtains. Figure A-1 is a graph of $P(\theta)/\mu$-vs-θ/T for various values of P_{ON} (hence μT), plotted by evaluating (45) directly. For values of P_{ON} of 0.6 or less, the limit of (47) is achieved within a few periods, while for $P_{ON} = 0.8$, the function $P(\theta)$ is still oscillating substantially about the limit after four periods. This behavior is intuitively appealing; as the events grow more rare in occurrence, the probability of occurrence becomes less dependent upon the time of occurrence of any given event. But if the probability that an event is ongoing approaches unity, they occur with near certainty one afte the other and the function $P(\theta)$ must degenerate toward a sequence of equally-spaced delta functions. Figure A-1 exhibits the near-constancy of $P(\theta)$ for $P_{ON} = 0.2$ and the approaching onset of the latter pathology at $P_{ON} = 0.8$.

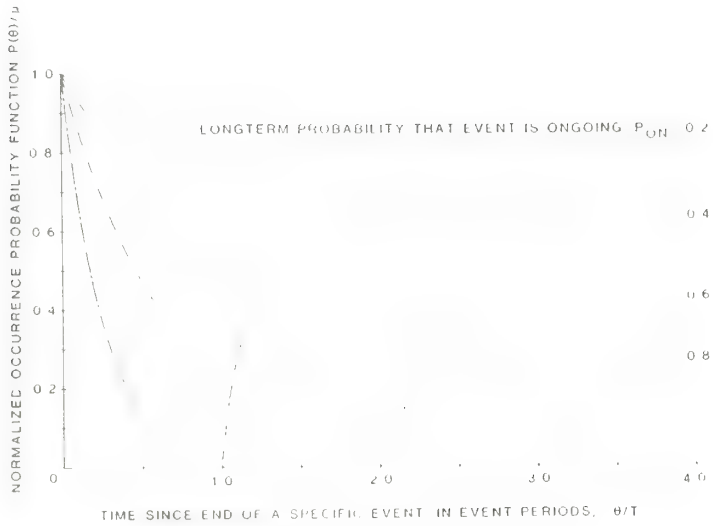

Figure A-1.--Probability density for event occurrence following termination of a given event. The asymptote for each curve is $1-P_{ON}$, since the plotted variable, $P(\theta)/\mu$, is normalized by the mean occurrence rate (Equation 45).

One may further note that each term in the sum of eq. (45) is the probability of observing exactly k events in the total event-occurrence time span θ-kT when the events occur at random with constant mean rate μ; i.e., the number of events, k, is Poisson distributed[1] with mean $\mu(\theta-kT)$.

Evaluation of Power Spectra

Using eq. (45) in the integral in eq. (38) gives the power spectral density of the process described. To obtain a closed form expression, we must evaluate the integral I:

$$I = \int_0^\infty P(\tau)\cos(\omega\tau+\omega T)d\tau = \sum_{n=0}^{\infty}\int_{nT}^{(n+1)T} P(nT\leq\tau\leq(n+1)T)\cos(\omega\tau+\omega T)d\tau \tag{48}$$

$$= \sum_{n=0}^{\infty}\sum_{k=0}^{n}\int_{nT}^{(n+1)T} \mu\frac{(\mu(\tau-kT))^k}{k!}\cos(\omega\tau+\omega T)\exp(-\mu(\tau-kT))d\tau \tag{49}$$

in which the circular frequency $\omega = 2\pi n$ is used. Changing the integration variable to $\mu(\tau - kT) = x$ and interchanging the order of the two sums eliminates one summation and simplifies the result to

$$I = \sum_{k=0}^{\infty}\frac{1}{k!}\int_0^\infty x^k\cos((k+1)\omega T + \omega x/\mu)\exp(-x)dx. \tag{50}$$

---

[1]An alternative derivation of (45) can be based on this fact, using the recursion (16) to evolve the probability $P_n(\theta)$ that an event starts at $\theta,\theta+d\theta$ given the occurrence of n intervening events. Analyst Fred Bratten (USDA Forest Service, PSW-Riverside) commended this approach to the author.

Expressing the cosine in imaginary exponent form and interchanging the order of summation and integration gives the form

$$I = \frac{1}{2}\int_0^\infty \exp(-x)[\exp(i(\omega T + \omega x/\mu) + x\exp(i\omega T))$$

$$+ \exp(-i(\omega T + \omega x/\mu) + x\exp(-i\omega T))]dx \tag{51}$$

where i is the unit imaginary.

In (51) each term is absolutely convergent, and the results are simple complex fractions

$$I = -\frac{1}{2}[(1 - (1 - i\omega/\mu)\exp(-i\omega T))^{-1} + (1 - (1 + i\omega/\mu)\exp(i\omega T))^{-1}]. \tag{52}$$

Combining terms and simplifying gives the compact result

$$I = -\frac{1 - \cos(\omega T) + (\omega/\mu)\sin(\omega T)}{2(1-\cos(\omega T)+(\omega/\mu)\sin(\omega T))+(\omega/\mu)^2}. \tag{53}$$

Since the factor in (38) involves 1+2I, the result is even simpler due to cancellation of terms, leaving, finally

$$\frac{S_x(n)}{P_{ON}A^2T} = \frac{32\sin^4(\frac{\omega T}{4})}{(\omega T + \mu T\sin(\omega T))^2 + (2\mu T\sin^2(\frac{\omega T}{2}))^2}. \tag{54}$$

The limiting forms of (54) have the correct behavior, as can be verified by direct computation. When the events become exceedingly rare, the autocorrelation function has a nonzero value only over the period of a single event, leading to

$$\lim_{\mu T\to 0} \frac{S_x(n)}{P_{ON}A^2T} = \frac{2\sin^4(\frac{\omega T}{4})}{(\omega T/4)^2}. \tag{55}$$

When the opposite condition obtains, so the square wave becomes a continuous steady signal, the power spectrum must degenerate to series of delta functions at odd multiples of the period T. The form of (54) does so in that

$$\lim_{\mu T\to\infty} \frac{S_x(n)}{P_{ON}A^2T} = \frac{2}{(\mu T)^2}\tan^2(\frac{\omega T}{4}), \tag{56}$$

which vanishes everywhere except for being indeterminate at $n=\omega/2\pi=(2M+1)/T$, where M is an integer.

The power spectral density as expressed by (54) is graphed in the text for various values of the parameter μT, expressed in terms of P_{ON}. These figures illustrate that the shape of the spectrum is quite insensitive to the value of P_{ON} unless $P_{ON} > 0.8$. This is consistent with the generally benign behavior of the probability function $P(\theta)$ for $P_{ON} < 0.8$. In other words, most of the variation of $S_x(n)$ with frequency is contained in the dependence on ωT expressed by the limiting form for $P_{ON} \to 0$ unless $P_{ON} > 0.8$. The amplitude factor $P_{ON}A^2T$ and the frequency at which the first maximum of (55) occurs ($nT \doteq 0.742$) suffice to determine the greatest part of the whole spectrum for modest values of P_{ON}. This fact affords considerable simplification in the application of the derived power spectrum intended here.

Albini, Frank A. Potential spotting distance from wind-driven surface fires. Res. Pap. INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 27p.

Equations are presented by which to calculate the maximum firebrand particle lofting height from wind-driven line fires in surface fuels. Variables used are the fuel type, described as one of twelve stylized models used for fire behavior prediction, the fire intensity, and the mean windspeed at 10 m height. Using the maximum particle lofting height, downwind drift of the firebrand particle during lofting and maximum spot fire distance are calculable from equations presented here and published elsewhere. The model upon which the equations are based assumes that the particle is transported upward by a two-dimensional thermal. Such thermals are assumed to be generated by variations of fire intensity with time. Both assumptions are speculative and probably not subject to direct test, so the model is considered tentative. Field test of the model predictions will reveal whether or not it provides useful estimates of spot fire distance.

KEYWORDS: spot fires, spotting, firebrands

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Richard J. Barney

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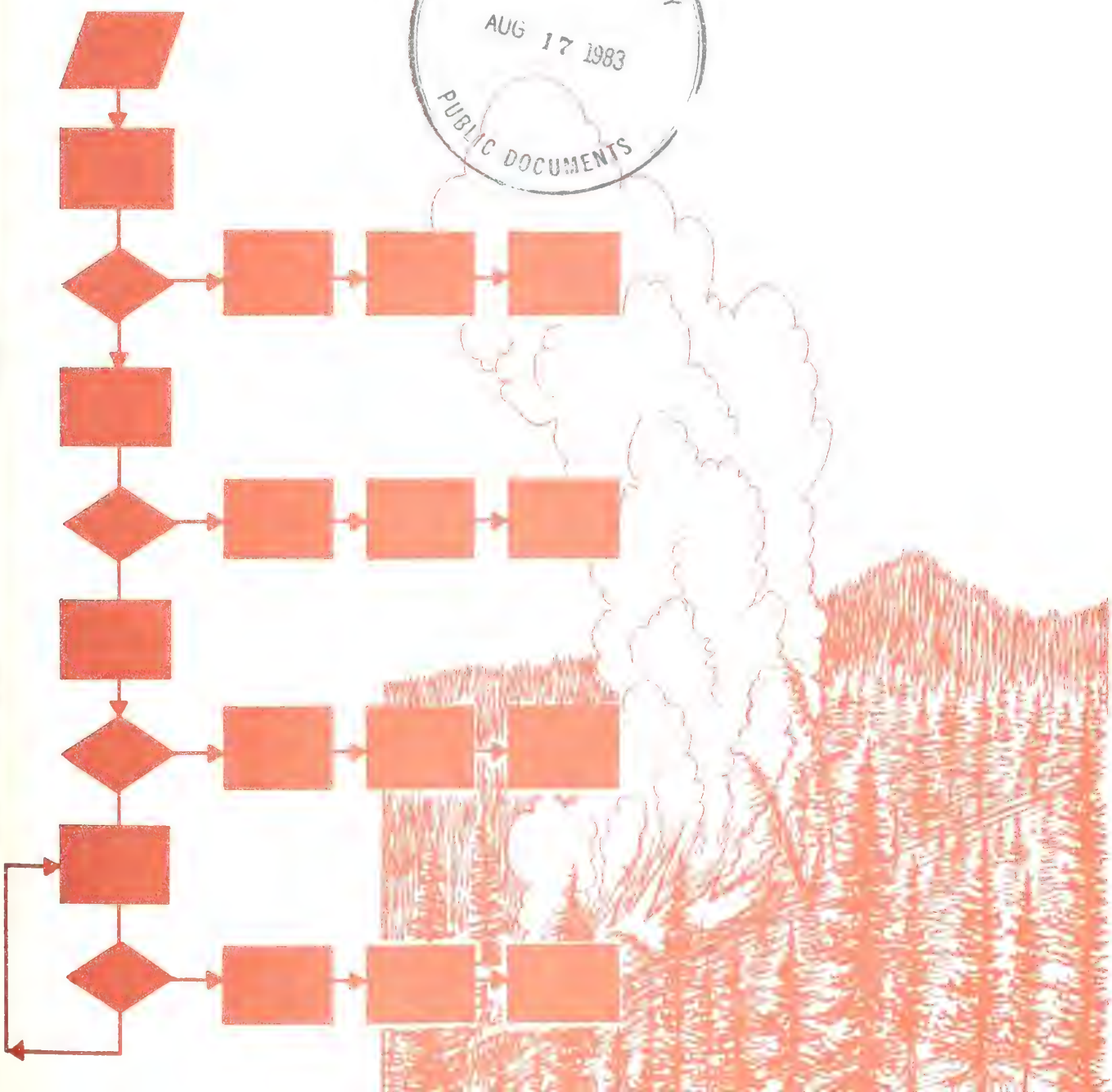

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RESEARCH SUMMARY

This report describes a conceptual model that provides a framework for the components of fireline production. Other conceptual or operational fire-related models may be linked with this production model. Major components and relationships are diagramed.

Fireline production is a component of the broader fire suppression process. The production of fireline has been defined by four phases: management phase, theoretical phase, application phase, and evaluation phase. The model provides a basis for standardizing components, which helps insure future compatibility. This conceptual approach enables managers to tailor production outputs to a specific site and situation. Application of the model should improve planning and fire management.

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Fireline Production: A Conceptual Model

Richard J. Barney

INTRODUCTION

Fire suppression capabilities and rates of production have long been of interest to firefighters and fire managers. The need for and use of fireline production information has been well documented in agency manuals and planning procedures. Fireline production information answers questions like the following:

1. What are the production rates and capabilities of crews and mechanical equipment for producing effective fireline under various environmental and site conditions?
2. How many firefighters or how much equipment is needed to contain or suppress a specific fire?
3. How wide must the fireline be to hold?
4. How does the width of fireline vary with changes in fuel, weather, and other site factors?
5. What are the optimum combinations of people and equipment such as tools, dozers, and tankers to develop the best production rate?
6. How do we obtain production rates for combinations of line-building methods?

Such information is necessary to determine the personnel and equipment required to accomplish a given job, and to obtain the most return for each dollar spent on fire suppression efforts. Cost information, including resource costs on fires, by its very nature, is linked heavily to production information.

Historically, fireline production information has considered only a limited number of input variables. Essentially, production rates considered only crew size, training, or experience level and a broad fuel classification. Fuel classification was further broken down into rate-of-spread and resistance-to-control categories. Resistance to control provided a measure of how much fuel had to be removed and often reflected the amount of crosscut saw work that was necessary, or some other measure of line construction difficulty. Each regional set of resistance-to-control guides was developed based on individual experience, rather than from an in-depth objective study. Such experience-based information was and still is a very important source of data. The classification schemes often used relative values ranging from a "low" to an "extreme" category. Sometimes a term like "medium" was defined, but usually not in quantitative terms.

The same general scheme was used to rate and classify fire rate of spread. The subjective rating usually ranged from low to extreme. Again, categories were ill-defined in quantitative terms. The most popular method to rate fuels was through pictures or narrative descriptions. When a different fuel type was encountered, it would be given a rating such as H-M (high rate-of-spread potential—medium resistance to control). Most of the production information has been expressed in these types of terms, even in some of the more recent studies.

PAST AND CURRENT WORK

Fireline production information has been gathered since the turn of the century. In the mid-1930's, a considerable amount of information was developed. This may have been partly due to the formal beginning of fire research, as well as the need for better data to support "new" Forest Service policies. Hornby (1936) listed the most important factors that influenced rate of construction of fireline per man-hour:

1. Fuel resistance to control
2. Method of attack
3. Kinds of tools, equipment, and food provided
4. Efficiency of directing officers
5. Training and experience of firefighters
6. Physical and mental abilities of firefighters
7. Size of crew
8. Size of fire
9. Aggressiveness and heat of fire
10. Prevailing atmospheric temperature
11. Fatigue
12. Darkness

These items seem appropriate today, with some slight modification of terms to fit current systems of operation and available research data. Work of Abell (1937), Buck (1938), and Hanson (1941) provides additional regional input to the fireline production rate data bases. In 1969, Storey summarized existing productivity and line-building data. He felt there were adequate hand-crew data available, but quality was questionable. Bulldozer data were found to be in a similar condition. He felt one shortcoming of the production data was that they lacked good information on fire behavior. In addition, the data lacked applicability on a broader geographic basis. He felt a national system for rating fuels for fire rate of spread and resistance to control was urgently needed.

In addition to Storey's summary work, several efforts have been made regarding fireline production. These efforts range from the theoretical efforts of McMasters (1963) to hand-crew studies of the California Department of Forestry (Weaver 1976). Some of the complaints with earlier studies—inadequate ties to conditional and site variables—are also appropriate for these efforts. Barney and Noste (1973) attempted to tie both crew and machine production efforts to conditional and site parameters in Alaska, but data collected were limited. In the early 1970's, Lindquist (1970) developed crew production data, but, again, this work was not tied to environmental, site, or other factors. Production rates for various line widths were determined, however. In the middle and late 70's, the USDA Forest Service Equipment Development Center, Missoula, Mont. (Ramberg 1974), carried out fireline production studies in conjunction with their firefighter fitness and physiological research. Although they found the same kind of wide variation

in older study data, they concluded that fireline production rates in current guides are too high—50 to 100 percent—in most cases. Murphy and Quintilio (1978) developed crew production rates that included some details for fuels and construction resistance. The most recent efforts in attempting to make sense out of production information are by Haven and others (1983). Although these efforts are not yet completed, they essentially update the earlier work of Storey.

OBJECTIVE

The high value of resources today, laws, policies, and the vast array of more sophisticated and expensive equipment dictate against use of simplistic systems and limited data bases. Suppression capabilities relative to production need to be expressed in terms that go beyond simply the time required to build a fireline from point "A" to point "B". Management decisionmakers need more detailed information and more precise tools. Suppression capabilities need to be expressed in terms that lend themselves to more sophisticated analysis and application. Recent developments in fire models, fire danger ratings, and economic evaluation procedures all require more improved information. Links should be developed among various suppression capabilities, fire characteristics including site and behavior factors, and situation parameters such as management objectives, economic criteria, and impact assessment. Research outputs must also be compatible with operating and planned data synthesis and analysis techniques.

This paper is an attempt to define the process of fireline production. A conceptual model is presented and discussed in an attempt to overcome problems found in earlier production data. By providing a more detailed view of the system, it is hoped the appropriate data can be provided in such a manner as to become more universally understood and useful. A model such as presented here provides a logical basis for linking segments of the fire management system.

FIRE SUPPRESSION SYSTEM

A general model of the fire suppression system is shown in figure 1. The process begins with the detection or discovery of an actual wildfire through either traditional detection and reporting processes or by a simulation of a fire-start in a gaming process. The first attack follows detection, assuming action is to be taken. The goal of the first or initial attack is to contain the fire, suppress it, and mop it up until it is declared out. There are two possible outcomes—success or failure. If sufficient force is promptly dispatched to the fire, reaches it, and takes sufficient action, the fire will be contained and, eventually, put out.

During initial attack, fireline production is different in many respects from later reinforcement and sustained production. In initial attack, the most active areas are usually hit first, then the less active or nonactive areas. The fire is "hot-spotted," or cooled down, then ringed with some form of line. The basic approach is to contain the fire at a rate faster than the fire is spreading, so as to surround and eventually control the fire. If the suppression force is successful during its initial attack phase, the fire is contained, mopped up, and completely extinguished. If, on the other hand, first efforts are not sufficient to accomplish the goal, reinforcements or additional time, or both (wait for evening, fuel change, etc.) will be necessary. Fire behavior is predicted and enough additional personnel and

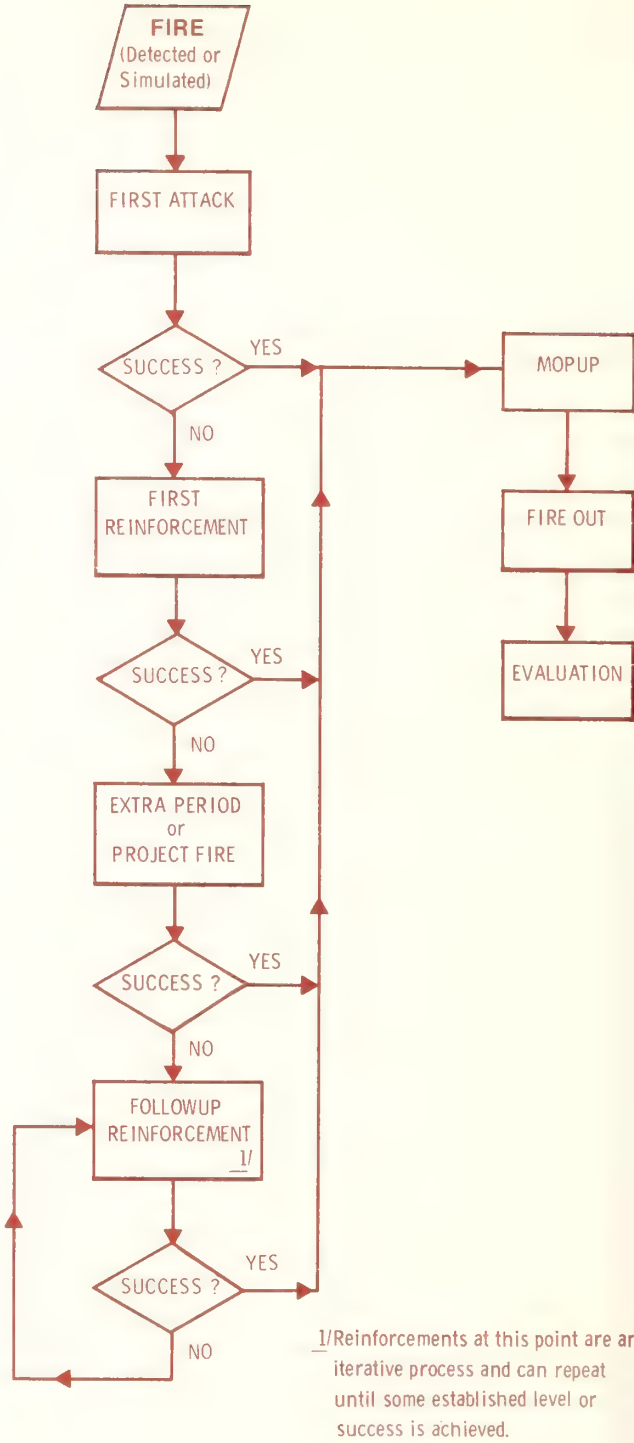

Figure 1.—A simplified model of fire suppression efforts.

machinery are dispatched to retard the fire growth at a rate faster than the spread of the fire. Disregarding other variables such as weather, fuel, and site conditions, the larger the fire, the more total work effort is required and the more difficult the task becomes to contain it. If sufficient effort is provided with the first reinforcements, success will follow. If this level of effort is not adequate, failure will occur. The type of production usually found in first reinforcements is often similar to the "hot-spotting" found in initial attack. However, with greater suppression resources, the tendency is toward more methodical effort.

When first reinforcements fail, there is a chance that the fire is or will become an escaped fire and possibly a project-size fire. When this happens, the situation must be reevaluated, additional forces added, or effort of existing forces continued under different environmental conditions. The general goal is still to build fireline at a rate faster than the fire perimeter is increasing. Modified use of this concept, such as herding the fire through judicious use of fireline into an area of flat ground, light fuels, rivers, lakes, etc., is also practiced. Depending on the success of subsequent events, followup may be made and continued until reinforcements are either no longer available, economically inaccessible, or not needed.

As a general rule, the type of production in fire suppression moves from a quick assault action to a slower, more methodical construction procedure. It is, therefore, worth considering two and possibly more levels of fireline production rates by virtue of intent alone. Followup reinforcement can be an iterative process until success or some other cutoff level is reached.

FIRELINE DEFINITION

Fireline, by definition, is a manmade or natural barrier that impedes the progress of a fire traveling through ground fuels. More specifically, it has been defined as "that portion of a control line from which flammable materials have been removed by scraping or digging to the mineral soil." It is the author's contention, however, that when developing production information, there are two categories of fireline: (1) fireline constructed to bare mineral soil, and (2) fireline classed as "other." This latter category includes all processes and activities that produce a fire-stopping barrier without removing materials to mineral soil. Examples are areas wet down with water. Retardant could fall into this second classification if the fire's progress was stopped, not just retarded. Burned-out strips, "black line" established without the aid of water or retardant, or a beaten line such as created by flappers or sacks could also fall into this "other" fireline.

For the purpose of this paper, eight categories or components of fireline are defined. These can be found in any combination and are as follows:

1. Scratch line – hastily built, hit-and-miss line that attacks hot spots, but stops forward progress.
2. Wet line – line made by wetting fuels ahead of the fire by either ground or aerial application.
3. Black line – previously burned, or burning a strip with the express purpose of stopping the fire versus reinforcing other types of line.
4. Retardant line – line composed only of retardant and no other physical clearing which has been applied either from the air or the ground.
5. Mineral soil line – line built to mineral soil by hand crews or machines.
6. Vegetative clearing and modification – the enhancement of fireline through clearing, removal, limbing, or other modifica- [illegible] by hand [illegible] mechanical processes.
7. Natural barriers – line made through use of rivers, lakes, rockslides, and other natural barriers.
8. Cultural barriers – line made with roads, railroads, power line rights-of-way, and other preexisting manmade barriers.

SUPPRESSION CAPABILITIES OR LINE PRODUCTION

To date, most fireline production data are based on point-to-point construction only. There is a wealth of qualitative production interpretation and outputs which are ranked high to low for rates of construction. This approach may be desirable from an operational application standpoint, but it is difficult, if not impossible, to compare, pool, or analyze such data. Many of the specific elements that can cause changes or affect rates of production are considered in a general sense, if at all. Limited ties, if any, are made with fire behavior characteristics, with the exception of spread rates.

Producing fireline at a rate that is fast enough to exceed the fire growth rate is only one of our concerns. We must also consider economics and conditional and site factors in the overall model, not just assume that the line is adequate and will hold. Fireline production must further be viewed in a total system context, covering everything from detection time through mopup, and effects of suppression action must be seen in terms of land management objectives. Fireline production information should also link with existing systems and models as completely as possible, such as National Fire-Danger Rating System (NFDRS), fire spread models, fuel models, etc.

Considering the background and evolution, as well as current needs and applications for fireline production information, a revised approach to the issue seems to be appropriate. The problem of developing a fire suppression production model is broad and complex. Such a task demands consideration of almost an infinite variety and combinations of items. In order to approach the task in a manner that will facilitate discussion, it has been segmented. The components are often interrelated, but the segments outlined should help in the discussion and understanding.

The process of fireline production is illustrated in figure 2. Four phases have been delineated—the management phase, the theoretical production phase, the application phase, and the evaluation phase. Under the management phase, policy, management goals, and objectives provide inputs and eventual decisions to take suppression action, as well as define the types and extent of such action. Once a decision is made to suppress the fire, the theoretical production phase is implemented. In this phase, the suppression resource options are reviewed and modified, as appropriate, and this theoretical information fed into the application phase. The application phase converts the theoretical production rates into actual production projections based on existing conditions. In the final evaluation phase, the tactics, along with the adjusted production rates, are used to determine costs, cost-benefits, or other effectiveness or evaluation information. Also, this last phase includes an evaluation of effects and probability of success. Depending on the constraints at the outset, the fire is either suppressed after the first time through, or else sufficient iterations through the system are made until all conditions are satisfied.

Management Phase

Application of the fireline production information can fit into three basic categories: (1) wildfire use, (2) prescribed fire use, and (3) use in simulation. Information can be used to address needs in both action (real-time) situations and planning through all levels of resolution and time horizons. The management phase includes all legal, organizational, and operational constraints or guidelines that affect the situation under consideration. Perhaps the most important consideration here is the management objectives. What is to be done with the resource and the consequences of action or nonaction are very important considerations. The effect of the suppression action itself, which is closely related to fireline production, is today often as important as many other considerations related to fire. Environmental concerns and consequences also play a major role in decision and allocation processes. This phase is really the key in subsequent action determination, including the selection of type, timing, and placement of one or more fireline production options.

Theoretical Production

The theoretical production phase encompasses all the fireline construction and suppression production resource options. In resource options, all types of personnel, equipment, and material used to produce fireline are considered. In this phase, theoretical rates are established. In addition, substitution possibilities are explored within or among production categories. For example, a TD–24 dozer might be directly substituted for a D–8 dozer similarly equipped. One 1,000-gallon pumper truck might be substituted for two 500-gallon pumper trucks, etc. Combination operations can also be developed using numerous combinations of both personnel and equipment to develop single production rates from multiple inputs. In this phase, the ultimate output is called a theoretical or potential output rate. This rate is unencumbered by any factors that might cause it to change. Change in rate is discussed in the next section.

Application Phase

The application phase is the phase in which the basic theoretical production rates are modified to meet an array of conditioning factors. The adjusted production rates are further modified by (1) the availability of production resources—if limited quantities or no specific resources are noted, it is not reasonable to consider them in determining rates; (2) the tactic, or type of attack and type of line to be constructed, as influenced by fuel, fire, and topographic constraints, is the final modifier to the system. The modified production rate value put out at this point is the value needed for each specific application.

Evaluation Phase

The manager can determine such items as cost per unit, cost-benefit, probabilities of success, strength of force requirements, and a myriad of other values. This final phase has been called the evaluation phase. The decision to either go to work on the fire or redefine the suppression strategy is made only after the projected results are compared with the management objectives

FIRELINE PRODUCTION CONCEPTUAL MODEL

The general process flow diagram (fig. 2) can be expanded, providing additional detail. This detailed expansion can be considered a conceptual model for fireline production. Figure 3 illustrates the model, including the four phases and major components. More detailed explanation of some components will be developed in subsequent paragraphs. Numbers in parentheses within the diagram boxes are used to key the item to the text explanation.

Phases in this presentation of the model are similar to those discussed in the previous section. The only difference here is that the diagram orientation has changed. In the management phase, several decisions or conditions must be met before proceeding. First, the fire event begins the flow of action. This fire event can be a wildfire, a prescribed fire, or some form of simulated fire. Once the decision to suppress has been made, we can proceed through the model. The decision can even be "I think I want to suppress, but am not sure." In any case, by running through the model, one can assess the merit or relevance of a variety of information, which can contribute to the ultimate decision.

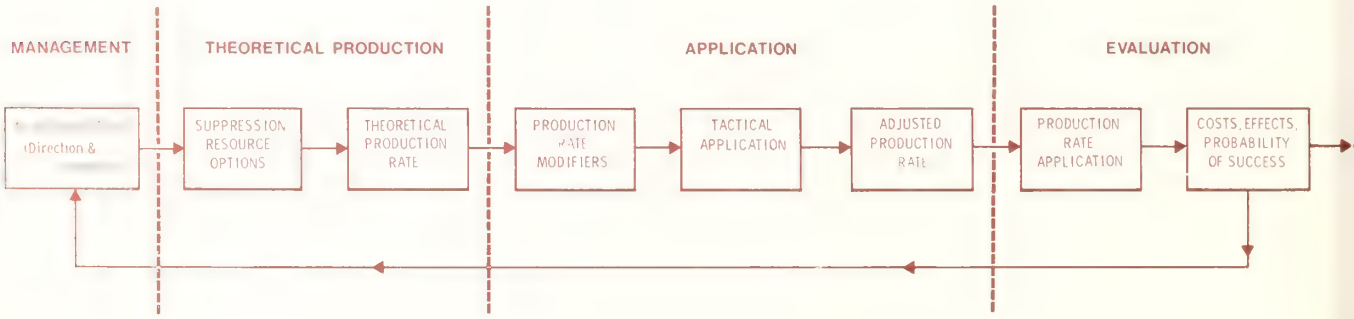

Figure 2.—General process flow for fireline production.

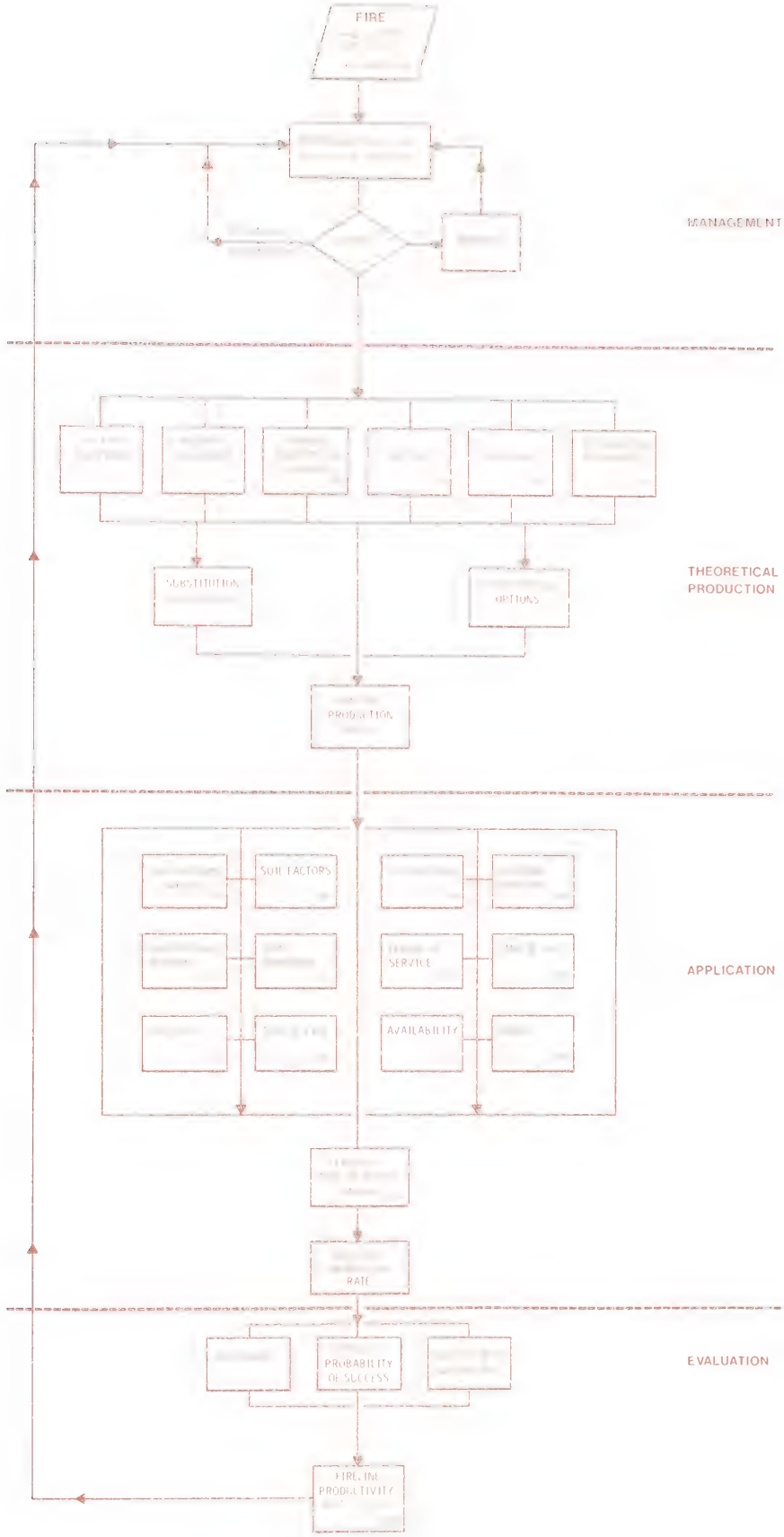

Figure 3.—Fireline production conceptual model.

In the theoretical production phase, we make first contact with the machines, personnel, or other devices that can be brought to bear in the construction of a fireline. In this model, (1) heavy equipment has been defined to include primarily dozers (tracked equipment with push blades) of the D–7 size class or larger, and (2) medium equipment has been defined to include D–4 through D–6 size dozers and fire plows and similar units. Water-hauling and water-handling equipment mounted on its own transportation (truck) is characterized by tankers, skidders, pumpers, or engines (3). This category includes equipment ranging from 100-gallon slip-on tank and pump units to 10,000-gallon units that are designed to haul, pump, and discharge water through hoses and nozzles. The aircraft category (4) includes all models of both fixed- and rotary-winged (helicopters) aircraft. Their applications may be both tactical and logistical.

Personnel (5) is perhaps one of the most complex categories of production resources. It includes all configurations of personnel forces assembled to suppress fires in some organized manner. Breakdowns within this group include, but are not limited to, numbers, age, training, types of crew, and experience. The possible combinations of utilizing personnel are large.

The final category of production resources—specialized techniques (6)—is, in essence, a catchall. This category provides a classification niche for anything not already covered. Production resources here are exemplified by the modified logging equipment, trenchers, and other equipment that does not fit into previously defined categories. Explosives, a promising technique in the Western States and Alaska, also fall into this category.

The numbers of boxes representing production resources certainly could be increased. The lists and specifications within each box could be extended. Grouping similar types of resources limits the diagram's complexity.

As pointed out earlier, most of the production resource options have a substitute that will produce a similar rate of production. In the case of heavy and medium equipment, one brand may be substituted for another with similar specifications, resulting in the same production potential. A helitack crew might be substituted for a smokejumper crew of similar size, etc. The important point is that specific production resources can be substituted for others if a substitute resource is available.

Another important option—combining resources—exists to develop similar production rates. Essentially, what this means is that for a vast array of equipment, pumpers, aircraft, personnel, and specialized techniques, combinations can be assembled to produce a similar rate of production. For example, if one D–8 breaks down, it might be replaced by a D–4 and a D–6 tractor, along with a saw crew, to give a comparable rate of fireline output. Again, many possible combinations will develop a required rate of production.

By using substitute possibilities, combined options, or basic production rates, we can determine what an unencumbered production rate or rates would be. An unencumbered or potential production rate is essentially a theoretical rate or optimum condition rate. Before it can provide useful information in an application sense, it must be tempered by a host of modifying factors. These modifying factors are both site- and situation-specific, which make them directly related to application directions.

The factors that modify the theoretical production rates at this point are of both a static and a dynamic nature. Figure 3 illustrates in the application phase those specific items or class of items that are felt to be most important in accounting for rate changes. In addition, these factors are also, for the most part, important in linking with other operational and conceptual models.

Fuel factors (7) for naturally occurring biomass in the field are important not only in respect to their direct effect on fire, but also in their direct effect on rates of production. Specific items such as types of material, quantity, spacing extent, and environmental conditions are all important considerations in modifying rates of production; for example, the numbers of logs of a certain size class per unit of line distance encountered affect the output rate. Other appropriate characteristics specific to fuel can similarly be considered.

The kind of material in which the line is being built may also play an important role in production modification. Soil factors (8) that can be involved include soil types (sandy, clay, loam, peat bog, etc.). The amount, size, and distribution of rocks are also important. If the soil is an organic type, the soil depth and moisture condition can be of critical importance.

Site factors (9) include slope steepness, exposure, and similar physiographical features affecting both production and fire behavior. On the other hand, environmental factors (10) include wind, temperature, precipitation, cover, and other similar factors of both long- and short-term that tend to condition the site and may directly influence personnel. Fire danger rating is often used as an integration of these individual elements.

Suppression resources (11) and availability (17) are closely related. The suppression resources used at this level include those that might be brought to bear on a specific situation. This would include types, sizes, numbers, etc., or the more specific information of what is actually within reach of the suppression organization. Availability and suitability of resources ultimately assist in the determination of use. Availability can be cast in terms ranging from "Is such a resource available at all?" to "Is the resource available for use within the specified time frame?"

How a fire behaves or is projected to behave is, perhaps, one of the most important considerations in determining production rates. The fire behavior information (12) indicates the size of the job ahead. Rate of spread indicates the rate at which line must be produced to contain and suppress a fire. Flame length and fireline intensity indicate whether the fireline is feasible or not, how wide the line must be, and how close to the fire personnel and equipment can be placed, if feasible. The amount of mopup required and potential effects are a function of fuel characteristics, residence time, and afterburning. Therefore, fire behavior is a very important modifying factor in production.

The length of time personnel or equipment have been in service (13) has both positive and negative effects on production. In the case of personnel, length of service can improve experience and efficiency. Alternately, if we consider in-service as time on a specific fire or shift, there is a direct relationship to fatigue, mental attitude, and related conditions that affect production output. Equipment, including operators, can be affected in a very parallel way. The older the equipment and the longer it has been used, the more prone it is to breakdown. Therefore, the administrative constraints of total life as well as shift time of equipment can be a tempering factor in output. Also, administrative and legal constraints on the use of personnel and equipment, maintenance, safety, etc., impact output.

Directly related to the service factor is time of day. At night, fireline production is much different than during the day (14). Heat, light, temperature, visibility, and humidity all affect personnel, equipment, fire behavior, and other factors in the production of fireline.

Fuel and food (15)—fuel for machines and food for personnel—are mandatory production considerations. Short supply of food or unappetizing food adversely affects personnel in the same way as bad fuel or no fuel influences equipment operations.

The type of line (16) to be built is an important influence on production. The requirement for line is a function of the management objective. The kind of line to be built is determined by a combination of all factors just discussed. Important factors not covered can be handled in the "other" category (18). The fire strategy, planned or implemented tactics, including the timing and type of attack (19), will temper as well as be tempered by all these modifying factors to finally arrive at an adjusted production rate.

Once an adjusted production rate is available, the number or numbers can be used in the evaluation phase. It is at this point that management information is put into a form for either the decision to go to work or to go back and try a different mix or approach to satisfy the objectives. The fireline rate productivity value (20) should, at this point, be expressed in terms of unit of line per cost, or time or resource saved, or any appropriate unit or units that allow the decision criteria to be evaluated and met.

SUMMARY

In planning, action, or research, the utilization of the conceptual fireline production model as outlined in the previous pages can enhance all efforts. First, the parts and their relationships are defined, allowing the linking with other operating models, such as fire behavior and fuel models, as well as simulation models under development or yet to be developed. Standardization of elements is also a key to future compatibility of components.

Perhaps most important will be the ability of managers to tailor production outputs to their specific conditions. Development of functional relationships through application of the model will facilitate all forms of calculations. This system for determining and applying fireline production information will improve planning and fire management through a more complete and common understanding of the processes involved.

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A conceptual model for fireline production is presented. The model provides a framework for the components of production and indicates logical linking points for other conceptual or operational models. The diagrams offer a system to enhance fire management and land management planning through an understanding of the fireline production components and process.

KEYWORDS: fireline production, fire management, conceptual model

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Salvage and Thinning Operations in Second-Growth Ponderosa Pine Stands

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RESEARCH SUMMARY

Management of small-diameter (less than 9 inches diameter at breast height) timber has long been a major problem. Costs of operating conventional harvesting equipment in these stands have generally exceeded the value of the recovered products. In addition, the equipment has often irreparably damaged residual trees. The Northern Rocky Mountain area has many thousands of acres in need of thinning, and the utilization of these trees would enhance the area's present and future timber supply.

This report describes and discusses a harvesting system made up of commercially available equipment and modified farm tractors that has been successfully used to salvage and thin second-growth ponderosa pine stands. Commercial equipment consisted of feller-bunchers, a skidder, and a chipper. Farm tractors were equipped with grapples and metal reinforcings to adapt them to forest use.

Two studies made in the same general area are described, as well as procedures for recovering multiple products. Hog fuel, stud logs, saw logs, house logs, fenceposts, and pulp chips were the products evaluated. Economic analyses indicate that if suitable markets are available within a reasonable distance wood can be harvested in these small-size tree stands at a profit.

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Salvage and Thinning Operations in Second-Growth Ponderosa Pine Stands

John R. Host
David P. Lowery

INTRODUCTION

Two often-neglected wood resources are timber removed in precommercial thinnings and postharvest logging residue, consisting of branches, tops, and broken pieces.

The small log resource is vast. In Idaho and Montana, about 30 billion ft^3 of wood is in trees 5.0 to 8.9 inches (12.7 to 22.6 cm) diameter breast height (d.b.h.). Detailed data are available (Troutt 1979) for small-diameter lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) stands, which make up the largest part of this resource. The information should be generally applicable for all species in this size class, including ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.).

In lodgepole stands, through one rotation, about 65 percent of the stems are in excess of growing stock needs. Many of these could be removed as small logs. Removal would increase the total volume from any given stand by as much as 30 percent during each rotation. In addition, rotation length for lodgepole stands on average sites could be reduced from 100 to about 80 years if all thinnings were accomplished in a timely manner.

In recent years, considerable research has been devoted to inventorying, describing, and evaluating potential uses for postharvest residue. About 10,000 acres (4 050 ha) in the Northern Region of the Forest Service are clearcut annually, and many tons of residue are generated on each acre. Historically, the cost of collecting and transporting residue has made its use uneconomical, and it was burned on the site. However, innovative logging and timber sale methods now are being used to concentrate much of the logging debris at the roadside.

Timber supplies obviously would be enhanced if small-diameter trees and logging residues were better utilized. Landowners would realize a number of benefits, including (1) greater spacing and faster growth for residual crop trees, (2) removal of insect-infested trees and slash that should reduce insect populations and thus future tree mortality, (3) improvement of stand esthetics, (4) reduction of potential fire hazards, and (5) more open stands that provide easier access for future salvage, if necessary, and improved forage growth for livestock and wildlife.

To obtain additional information on utilization of small-diameter trees and logging residues, two studies were made of various harvesting systems applied in ponderosa pine stands. The studies were made in the same area, and many of the cooperators, personnel, and pieces of machinery were the same. One study (study 1) was made in January 1977. The second, more detailed study (study 2) began in September 1980 and lasted 6 months. Results of the studies are discussed separately in this report.

STUDY AREA DESCRIPTION

The study area was located on privately owned land in the Blackfoot River valley about 40 miles (67 km) northeast of Missoula, Mont. (fig. 1). The terrain is gently rolling with slopes averaging less than 10 percent.

Figure 1.—Map of Missoula vicinity showing the location of the study area.

The young ponderosa pine stands were established naturally following logging between 1885 and 1915. The trees are about 80 years old and the average d.b.h. ranges between 8 and 10 inches (20.3 and 25.4 cm). Most of these second-growth stands are overstocked, with basal areas in excess of 150 ft^2 (13.94 m^2) per acre.

An outbreak of the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) started in the area about 1972. Since that time the insect has attacked and killed a large number of trees of various diameters. The infested area, covering about 2,000 acres (809.4 ha), contains numerous patches of dead trees ranging from 1 to 10 acres (0.4 to 4.05 ha) in size.

Cutting in these stands has had several objectives: (1) to remove and utilize the dead trees; (2) to remove green trees considered to be attacked by the insects, thereby controlling, to a certain extent, the insect population; and (3) to reduce the basal area to about 90 ft^2 (8.3 m^2) or less per acre, a more satisfactory level for growth and prevention of insect attack. Other benefits included easier re-entry for salvage and harvesting and improved forage production for grazing.

STUDY 1

Increasing demand for wood products, concurrent with decreasing sawtimber supplies, is requiring the processing of smaller trees. Relatively high costs of harvesting small trees using conventional equipment have made operators hesitant to work in such stands. The objective of this study was to develop information on various systems that might be applicable to young, second-growth timber. Two groups of problems—forest management and harvesting—were addressed.

Some aspects of the forest management problem included: sanitation cutting, thinning, postharvest cleanup, residual tree response, and regeneration. Some harvesting facets examined were: felling and skidding equipment, skidding methods, log-making site, and slash disposal method and location.

Equipment used in the study consisted of gasoline-powered chain saws, a Melroe Bobcat (Model 1075) feller buncher (fig. 2), a rubber-tired Allis Chalmers farm tractor (Model 180) equipped with a rear-mounted homemade grapple, a John Deere rubber-tired skidder (Model 540) equipped with chokers (fig. 3), a Farmhand tractor with a hydraulic lift fork, and a Morbark chipper (Model 22).

Figure 2.—Shearing head on the Melroe feller-buncher.

Figure 3.—Farm tractor with homemade grapple attached.

Cutting Units

Four 2.5-acre (1.0-ha) units were used in the study. The detailed description of the procedure used on each study unit is as follows:

Unit 1.—On this unit all trees over 1 inch (2.5 cm) that showed signs of insect attack were felled and removed from the stand; healthy trees were not cut. The feller-buncher was used to shear (fig. 4) and group the trees for skidding. Trees too large for the shear were felled with a powersaw. Whole trees were grapple skidded to the landing where they were limbed and bucked into logs and fenceposts. Posts were made from those trees too small for stud logs and from tops between 6 and 3 inches (15.2 and 7.6 cm) in diameter. Saw logs were 33 ft (10.1 m) long. Unusable tops, branches, and small unmerchantable trees were chipped at the landing.

Unit 2.—This unit was logged conventionally. Powersaws were used to fell the trees, which were choker skidded. One skidder was used. Again, whole trees were moved to the landing where limbing and bucking took place. As in unit I, saw logs, stud logs, and fenceposts were cut at the landing and the unusable tops and branches were chipped. The minimum d.b.h. of the felled trees was 9 inches (22.9 cm).

Figure 4.—Sheared tree being lowered to the ground.

Unit 3.—All trees cut on this unit had a minimum d.b.h. of 9 inches (22.9 cm). Most trees were sheared using the feller-buncher. Trees too large for the shearing head, including 25 green trees, were felled with a powersaw by the machine operator. One skidder was used full-time, and a second, operated by a member of the landing crew, was used as needed. Entire trees were skidded by the grapple-equipped farm tractor to the landing where only saw logs were cut. The minimum top diameter inside bark (d.i.b.) was 6 inches (15.2 cm). The residue—branches and tops—was burned at the landing as it accumulated.

Unit 4.—This unit had essentially the same utilization standards as unit III. Minimum d.b.h. of the felled trees was 9 inches (22.9 cm). The trees on this unit were felled with a powersaw, limbed, and bucked at the stump with preferred log lengths of 26.5 ft (8.1 m) or 17.3 ft (5.3 m). The logging residue was piled and burned in the stand. The skidder with chokers was used to move the logs to the landing.

On units I and III, the feller-buncher operator was the primary skidder operator, did the powersaw felling, and was crew supervisor. The landing crew was made up of three or four persons. The sawyer did the limbing and bucking; the other crewmembers assisted with the limbing and bucking, did the skidding and decking of logs and fenceposts, and moved the residue to the chipper or burn pile. On units II and IV, a one- or two-man crew was used. One man did the powersaw felling, limbing, and bucking with some help cutting posts at the landing. The other crewmember operated the skidder.

The unit procedures are summarized in table 1.

Results and Discussion

The small size of the study units, 2.5 acres (1 ha), precluded continuous operation of all the machines. The feller-buncher completely felled and bunched the trees on one unit in less than 6 hours and the work on units I and III required less than 1.5 days. However, more than 2 days were needed to skid the trees on these units.

The tree felling data are presented in table 2. As would be expected, use of the feller-buncher was much faster than use of powersaws. The smallest number of trees was cut on unit III, which also had the greatest production rate.

Table 1.—Summary of the procedures and utilization standards for the four study units

Item	Unit I	Unit II	Unit III	Unit IV
Objective	Sanitation salvage	Thinning	Saw log removal	Saw log removal
Prescription	Cut all infested trees	Leave basal area 110 ft²	Cut all infested trees	Leave basal area 110 ft²
Thinning alternative	Precommercial	Commercial	Commercial	Commercial
Felling	Shear	Powersaw	Shear	Powersaw
Limb and buck	Landing	Landing	Landing	Stump
Skid	Grapple	Choker	Grapple	Choker
Residue treatment	Chip	Chip	Burn at landing	Burn at stump
No. in crew	3	1,2	3,4	1,2
UTILIZATION				
Size skidded	Full tree	Full tree	Full tree	Log length
Min. d.b.h.	1″ (2.5 cm)	9″ (22.9 cm)	9″ (22.9 cm)	9″ (22.9 cm)
Top d.i.b.	3″ (7.6 cm)	3″ (7.6 cm)	6″ (15.1 cm)	6″ (15.1 cm)
Products	Saw logs Posts Chips	Saw logs Posts Chips	Saw logs	Saw logs

Table 2.—Tree felling production rates on the four study units using the feller-buncher (shear) and powersaws

Item	Unit I	Unit II	Unit III	Unit IV
Method	Shear	Powersaw	Shear	Powersaw
Hours per unit	4.85	11.75	[1]2.65	8.26
Hours per acre	1.94	4.70	1.06	3.30
Trees per hour	[illegible]	38	69	40

[1]Does not include time required to fell 25 trees using the powersaw.

The number of trees taken from units I and II were 345 and 435, respectively. On unit III, 207 saw logs were produced. On this unit, because the skidding tractor did not have a push blade, the Farmhand tractor was used part-time to deck the logs and move the residue into the fire. On unit IV, 339 logs were skidded and decked conventionally at the landing.

The whole tree chipper's heel-boom grapple did not efficiently handle tops and small stems, but the chipper was the only one available. The objective of the chipping operation was to determine chip volume and quality obtainable in this type of operation. Production measures used were lineal feet of input, (tops and small trees) and weight of chip output. Chip production is shown in table 3. Average chip production for units I and II was 11.9 lineal feet/minute, 2.6 green tons/hour, and 0.9 dry unit/hour. This production was less than normal. In other studies, a Morbark Model 12 and a Trelan Model DL-18 had produced 15 and 13.7 units (200 ft^3 each)/hour, respectively.

As a result production data for a Morbark Eager Beaver model were used for cost analyses. This chipper has a lineal feed rate of 64.5 ft/minute, far exceeding the actual production rate of 11.9 ft/minute. The operational cost of the Beaver chipper was $173.76/day, of which $50 was for the machine and $123.76 for labor.

Personnel utilization.—The interchanging of positions by the crewmembers on units I and III caused some minor timekeeping problems. Unaccounted time expressed as a percentage of gross shift time is shown in table 4.

Two observers, one at the landing and one in the woods, were needed to time the skidding on units I and III. Unit III required the most supervisory time.

Potential productivity rates based on the time studies are shown in table 5. The data show that on units I, II, and III, the skidding rate determines the number of trees processed per hour at the landing, and on unit IV the felling rate determines the number of trees limbed and bucked per hour.

The average time and standard deviation for the critical skidding variables are shown in table 6. These data show the relationship between turns per hour, pieces per turn, and pieces per hour. Units I and III had a high number of turns per hour and a low number of pieces per turn due to the speed and low capacity of the grapple skidder. The opposite held for units II and IV, which had few turns per hour but a large number of pieces skidded per turn. As expected, the volume skidded was affected by the number of pieces and the average volume per piece. The largest volume skidded per hour was on unit I; unit II had the smallest volume skidded per hour.

Table 3.—Various measurements of chip production for units I and II

Item	Unit I	Unit II	Sum or average
Gross time (hours)	11.40	13.65	25.05
Lineal feet	9,177	8,660	17,837
Lineal feet/minute	13.47	10.57	11.87
Tons	31.87	32.14	65.01
Tons/hour	2.80	2.35	2.60
Bone dry units	12.3	9.7	22.0
Bone dry units/hour	1.08	0.71	0.88
Cubic feet	938	1,209	2,147
Cubic feet/hour	82.28	88.57	85.70

Table 4.—Unaccounted time by unit as a percent of shift time

Operation	Unit I	Unit II	Unit III	Unit IV
	Percent			
Woods	2	2	2	1
Skidding	4	2	3	2
Landing	2	2	4	1

Table 5.—Potential productivity rates based on time studies of the various logging functions by study unit

Function	Unit			
	I	II	III	IV
	Shear and bunch	*Saw*	*Shear and bunch*	*Saw*
Felling				
Trees/hour	[illegible]	38	[2]69	[illegible]
Limb and buck				
Trees/hour	[illegible]	55.7	30.4	46.3
Posts/hour	68	71	—	—
Skid				
Distance (feet)	874	1,195	730	1,032
Turns/hour	11.8	2.7	9.5	2.0
Pieces/hour	31.8	20.3	21.9	20.4

[1]Includes 46 trees felled with saw
[2]Includes 18 trees felled with saw

Table 6.—Average times and standard deviation, in parentheses, for the skidding variables on the study units

Variable	Unit			
	I	II	III	IV
	Minutes			
Hook	—	3.5 (1.0)	—	9.3 (2.0)
Unhook	—	.9 (0.5)	—	.5 (0.2)
Travel	3.8 (1.1)	10.3 (3.0)	4.5 (2.2)	15.7 (3.8)
Round trip (turn)	3.8	14.7	4.5	25.5
Delay	9	3.5	1.8	4.7
Landing	[illegible]	[illegible]	—	[illegible]
Turns/hour	11.8	[illegible]	9.5	2.0
Pieces/turn	2.7	[illegible]	2.3	10.3
Pieces/hour	31.8	20.3	21.9	20 4
Volume/piece (ft^3)[2]	18.4	14.5	20.1	21.2
Volume/hour (ft^3)[2]	585.1	294.3	440.2	432.5

[1]Landing time not recorded as the log handling was done with a machine other than the skidding tractor
[2]Does not include unmerchantable material to chipper.

Machine operating charges.—The wage overhead charges for the family-type operations used on units I and III were different from the labor overhead for units II and IV. In a family-type operation many overhead charges are omitted. Usual overhead charges, as a percent of direct wages, are:

Overhead charge	Percent
Holidays	4.5
Health and welfare	4.0
Industrial compensation	22.0
Unemployment compensation	6.5
Social security	7.0
Pension	5.0
Vacation	4.0
Total	53.0

In addition, travel time and transportation, not included in this list, may add 20 to 30 percent more cost.

The farm tractors used in skidding and material transport at the landing on units I and III have low capital requirements and a relatively long economic life under normal farming conditions (table 7). Normal life expectancy exceeds 20 years; a useful life of 15 years was used in the cost determination. (The AC 180 tractor was 18 years old and had been used 11 years for seasonal logging.) Additional years of logging would probably shorten a machine's useful life.

Comparison of the system productivities was based on the assumption that logging was continuous, although some machines and personnel were used only part-time. Because of differences between units, a standard unit was used to rate the study systems.

The standard unit had:

Logged volume/acre	2,430 ft^3 (10.8 M bd.ft.)
Volume/tree	18.1 ft^3
Trees/acre	134
Board ft/ft^3 ratio	4.45

Table 7.—Computation of hourly operating costs for the various study machines

Item	Machine					
					Powersaw	
	John Deere 540C	Farm-hand F10	Allis Chalmers 180	Melroe 1075	Woods	Landing
Initial cost ($)	48,000	10,000	21,000	46,000	[1]1,000	1,000
Salvage ($)	6,000	600	5,000	10,000	0	0
Life						
Hours	10,500	20,000	20,000	12,000	1,500	1,500
Years	7	15	15	10	1	1
Average Annual Investment ($)[2]	9,000	913	5,533	11,800	500	500
FIXED COST PER HOUR						
Depreciation	4.00	0.47	0.80	3.00	0.67	0.67
Interest @ 15%	.90	.09	.55	1.18	.05	.05
Taxes @ 3%	.18	.02	.11	.24	.01	.01
Insurance @ 1.5%	.09	.01	.06	.12	.01	.01
Total fixed	5.17	.059	1.52	4.54	0.74	0.74
VARIABLE COST PER HOUR						
Repair and maintenance[3]	3.60	0.42	0.72	2.70	0.60	0.60
Fuel[4]	2.10	.93	1.00	1.20	.30	.30
Lube[5]	1.05	.46	.50	.60	.15	.15
Tires	1.00	.70	1.00	.60	—	—
Subtotal	7.75	2.51	3.22	5.10	1.05	1.05
Wages - direct	7.83	6.00	8.00	8.00	12.50	9.00
indirect	4.07	3.12	4.16	4.16	6.50	4.68
Total variable	19.65	11.63	15.38	17.26	20.05	14.73
Total/hour	24.82	12.22	16.90	21.80	20.79	15.47

[1]Includes spare saw.

[2]Average annual investment = $\frac{\textit{initial cost} - \textit{salvage value}}{2 \times \text{number of operating hours}}$ + residual value.

[3]Repair and maintenance = 90 percent of depreciation.

[4]Fuel is based on $1 per gallon.

[5]Lube = 50 percent of fuel.

Production comparisons between the standard and study units were made on an hourly basis, thinning on a per-acre basis, and log production on the number of pieces handled or volume produced per hour. Comparisons of production time per acre and per hour are shown in table 8. Unit III required the greatest number of hours per acre, probably because a tractor was underutilized. The other unit systems were very similar in hours per acre required. Unit IV had no landing time because logs were cut at the stumps and only decked at the landing.

Product recovery.—Sanitation-salvage cutting removed 60 percent of the volume on unit III, 75 percent on unit I, and 77 percent of the volume on unit II (table 9). The commercial thinning, unit IV, removed 71.6 percent of the stand. All insect-infested trees were removed from unit I, only commercial sized trees were taken from unit III, and units II and IV were thinned to 110 ft^2 basal area. Logging residue was the cubic volume of material left on the area after the trees or logs had been skidded to the landing.

Table 8.—Production comparisons of man-machine hours per piece and per acre

Operation		Systems			
		I	II	III	IV
Felling	trees/h	[illegible]	38	[illegible]	40
	hours/acre	1.52	3.53	1.94	3.35
Limb and buck	trees/h	[1]46.0	[1]55.7	30.4	46.3
	hours/acre	[1]2.91	[1]2.41	4.41	2.89
	posts/h	68	71	—	—
	hours/acre	2.03	2.45	—	—
Skid	pieces/h	31.8	20.3	21.9	20.4
	hours/acre	4.21	6.60	6.12	6.57
Landing	pieces/h	34.7	95.2	11.9	NA
	hours/acre	3.86	1.41	11.26	NA
Total	hours/acre	[1]12.50	[1]13.95	23.73	12.81

[1]Does not include post-making operation.

Table 9.—Stand and treatment volumes on a per-acre basis for each of the study units

Item	Unit							
	I		II		III		IV	
	Ft[3]	*Percent*	*Ft*[3]	*Percent*	*Ft*[3]	*Percent*	*Ft*[3]	*Percent*
Initial volume	3,378	100.0	3,272	100.0	2,779	100.0	3,703	100.0
Removed	2,540	75.2	2,519	77.0	1,668	60.0	2,650	71.6
Residual volume	672	19.9	384	11.7	985	35.5	703	19.0
Logging residue[1]	167	4.9	369	11.3	[illegible]	4.5	350	9.4

[1]Logging residues 1 inch (2.5 cm) or larger in diameter

Products obtained from the stands were classified as follows:

1. SAW LOG pieces with at least 11.5 inches (29.2 cm) top diameter and 12 ft (3.7 m) long
2. STUD LOG pieces 5.5 to 11.5 inches (14.0 to 29.2 cm) top diameter and 8 ft (2.4 m) long
3. HOUSE LOG pieces 7.0 inches (17.8 cm) top diameter and any length over 12 ft (3.7 m).

To evaluate lumber and chip recovery, the saw logs from units I and III and units II and IV were combined. These logs were processed into ties, studs, and 2 × 3's. Lumber, tie, and chip recovery is shown in table 10. An estimated 8 percent of the green lumber recovery would be trimmed and lost because of checks and splits in the logs and lumber.

House log use was evaluated using a two-truckload sample of dead ponderosa pine logs obtained from a similar area adjacent to the study units. The sample was processed at a sawmill that had produced materials for a log home manufacturer (table 11).

Table 10.—Lumber and chip recovery obtained from two groups[1] of study unit logs

Item	Group 1 saw logs[1]	Group 2 saw logs[1]
Number of logs	473	446
Total log scale volume (bd.ft.)	31,665	24,297
Average log scale volume (bd.ft.)	67	54
Recovery		
Ties (bd.ft.)	7,586	2,990
Rough green lumber (bd.ft.)	25,038	26,410
Total	32,624	29,400
Lumber trim loss (8%)	2,003	2,113
Rough dry lumber (bd.ft.)	23,035	24,297
Chip volume (bone dry unit)	17.0	12.6
Ratio BDU/M bd.ft.	0.52	0.52

[1]Group saw logs were from units I and III, group 2 saw logs were from units II and IV.

Table 11.—House log sample and recovery of products used in log home manufacture

Item				
		SAMPLE LOGS		
Number of logs		278		
Lineal feet		7,851		
Gross bd.ft. log scale		11,950		
Net bd.ft. log scale		11,880		
Gross ft³ scale		2,685.4		
		PRODUCT RECOVERY		
	Lineal feet	*Bd.ft.*[1]	*Ft³*	*Percent*
House logs[2]	2,826	11,304	2,540.2	42.5
Rafters	456	1,596	358.7	6.0
Studs	4,488	2,991	672.1	11.2
Posts (7 ft)	238	71	16.0	.3
1 inch × 6 ft	176	88	19.8	.3
2 inches × 4 inches × 7 ft	469	312	70.1	1.2
Total	8,653	16,362	3,676.9	61.3
		RESIDUE		
Cull, chips, sawdust, bark			2,301.4	

[1]Board foot, cubic foot ratio was 4.45.
[2]House logs are 6-inch (15.2-cm) cants.

Fenceposts were cut at the landing from the tops and submerchantable trees of units I and II. The diameters ranged from 3 to 6 inches (7.6 to 15.2 cm). The following list shows post recovery on a per-acre basis:

	Unit I	Unit II
Number of posts	138	174
Volume, cubic feet	100.7	118.0
Volume, cubic meters	2.8	3.3

Tops, branches, and logging residue created at the unit I and II landings were chipped. An evaluation of the chips is shown in table 12. Lineal feet, the total length of stemwood chipped, not including branches and needles, was about 8,500 and 7,700 ft (2 591 and 2 347 m) for units I and II, respectively. Although unit I had about 10 percent more length than unit II, the gross weight of chips was less, probably due to the smaller trees taken from unit I or the higher percentage of green trees removed from unit II.

The density of the chips was affected by the amount of dead and branch wood. The chipped material of unit I was about 17 percent denser than the chipped material of unit II. Overall chip quality was below commercial standards with 35 and 49 percent of the chips unacceptable for pulping. The unbarked stems and the unscreened chips were the major causes for these high percentages, as shown in the following tabulation comparing woods and mill chipping:

	Woods	Mill
	Percent	
Bark content	19	0.7–2.5
Needle content	1	0
Fines content	17	4–10
Oversize content	5	0

A screening operation would have improved chip quality. Net chip recovery was estimated to be 12.3 and 9.6 bone dry units. This estimate was calculated by multiplying the acceptable chip percentage by the total chip weight, correcting for 29 percent moisture content, and dividing by 2,400 pounds (a bone dry unit).

Total product recovery is shown as a materials balance in table 13. The products were distributed according to unit except that saw logs from units I and III and units II and IV were combined as groups 1 and 2, respectively.

Logged volumes ranged from 60 to 77 percent and the residual stand ranged from 12 to 35 percent of the original stand volumes. Logging residues were lowest in units I and III which had 4.9 and 4.5 percent, respectively. Unit II had 11.3 percent residue and unit IV, 9.5 percent. The large amount of residue on unit II was due to choker skidding full trees, which damaged the residual trees and the operator not wanting to bunch and set chokers on the smaller stems.

Saw log recovery was the largest component on unit I, 81 percent; on unit II it was 76 percent. For the two units, the saw logs removed made up about 60 percent of original stand volume. Wood chips were the next largest component—15 percent for unit I and 19 percent for unit II of the volume removed. Approximately 4 percent of the volume was in fenceposts.

Secondary product yield was based on the two groups of saw logs. Approximately 70 percent of the saw log material was made into lumber or ties.

Economic analysis.—Our economic analysis compares production rates and costs for the different logging systems. Fixed and variable costs for the equipment used are included in table 7. The production rates for the four study units are shown in table 14.

Unit I had the lowest cost per piece, followed by units IV, II, and III. High landing costs adversely affected total costs for unit III. The data also show that the feller-buncher is less costly than the powersaw when compared on a trees-cut basis.

Table 12.—Data on chips produced on units I and II

Item	Unit I	Unit II
Lineal feet chipped	8,481	7,698
Gross weight (pounds)[1]	63,740	64,180
Chipped material (ft^3)	938.04	1,209.19
Density (pounds per ft^3)[2]	67.95	58.00
Percent acceptable chips	65.0	50.8
Percent needles	1.0	1.7
Percent bark	18.9	18.8
Percent oversized chips	5.0	5.0
Number of chip units	12.3	9.7

[1]Weight of chipped material in truck.
[2]Determined by dividing gross weight by volume.

Table 13.—Materials balance by logging unit on a per-acre basis

Item	Unit I		Unit II		Unit III		Unit IV	
	Ft[3]	*Percent*	*Ft*[3]	*Percent*	*Ft*[3]	*Percent*	*Ft*[3]	
Prelogged stand	3,378	100.0	3,272	100.0	2,779	100.0	3,703	100.0
Logged volume	2,540	75.2	2,519	77.0	1,668	60.0	2,650	71.5
Residues[1]	166.7	4.9	368.8	11.3	125.4	4.5	350.5	9.5
Residual stand	671.7	19.9	384.2	11.7	985.2	35.5	702.6	19.0
Logged material primary products								
Chips								
(acceptable)	242	9.5	190	7.5				
(unacceptable)	133	5.2	294	11.7				
Posts	101	4.0	118	4.7				
Saw logs	2,064	81.3	1,917	76.1				
Total	2,540	100.0	2,519	100.0				
	(71.9 m³)		(71.4 m³)					
Saw log recovery[2] secondary products								
	Group 1		Group 2					
Lumber	1,043	55.9	1,439	63.0				
Railroad ties	328	17.6	162	7.1				
Chips	472	25.3	653	28.6				
Residues	22	1.2	30	1.3				
Total	1,865	100.0	2,284	100.0				
	(52.8 m³)		(64.7 m³)					

[1]Does not include prelogging residues, which are negligible.
[2]Based on sample sawmill recovery study, units I and II = group 1 and units II and IV = group 2.

Table 14.—Comparison of tree to deck logging systems for the four study units

	Unit I	Unit II	Unit III	Unit IV
Felling				
Trees per hour	88	38	69	40
Cost per hour	21.80	20.79	21.80	20.79
Cost per tree	.25	.55	.32	.52
Limb and buck				
Trees per hour	46.0	55.7	30.4	46.3
Cost per hour	15.47	15.47	15.47	20.79
Cost per tree	.34	.28	.51	.45
Skid				
Trees per hour	31.8	20.3	21.9	20.4
Cost per hour	16.90	24.82	16.90	24.82
Cost per piece	.53	1.22	.77	1.22
Landing				
Pieces per hour	34.7	95.2	23.8	—
Cost per hour	15.47	15.47	24.38	—
Cost per piece	.45	.16	1.02	—
Post-making				
Posts per hour	68	71		
Cost per hour	15.47	15.47		
Cost per post	.23	.22		
Total Cost Per Piece	1.57	2.21	2.62	2.19
Hours	69.64	76.55	78.55	66.40
M bd.ft.	36.50	62.83	59.83	54.17
Acres	183.18	398.63	472.50	394.96
Hectares	517.53	728.50	863.66	721.91
Cunits	8.66	12.19	14.45	12.08
Meters[1]	11.11	15.64	18.54	15.50

[1]M bd.ft. = 2.36 m³. Chipping costs for units I and II are not included.

Table 15.—Income and cost data for the four study units on a per-acre basis

Item	Unit I	Unit II	Unit III	Unit IV
Gross income	1,552.82	1,565.38	907.55	1,442.26
Cost	183.18	398.16	472.50	394.96
Net income	1,369.64	1,167.22	435.05	1,047.30

Total costs and income.—Prices used to determine income were: $128/M bd.ft. log scale, $12/bone dry unit of pulp chips, and $0.69/fencepost. Cost data for the logging systems on the individual units are shown in table 14, and the income and cost on a per-acre basis in table 15. Hog fuel chips and fenceposts are included in the income for units I and II, as is the production cost of the fenceposts. However, because the chipper was of the wrong capacity, the chipper costs were excessive and are omitted. The data show that units I and II were the most profitable. These units also were left with a suitable stocking of young trees, and no postharvest treatment was necessary.

In addition to the income, other land management benefits were derived from operating in these young stands. Cleaning the stand will make future access easier. Removal of the smaller trees makes additional minerals and growing space available to the residual stand. Also, removal of the insect-infested trees should provide some protection to the crop trees. In addition, opening the stands should increase forage production and permit ready access for timber salvage or harvesting (fig. 5).

Land management consideration.—The unit data also provided information for comparing limbing, bucking, and slash disposal at the landing and the same operations at the stumps. Also, sanitation-salvage cutting could be compared with saw log removal.

Limbing and bucking at the landing reduced the skidding cost, especially if the trees contained more than one saw log. Another advantage of whole-tree skidding was reduction of slash in the logged area. Limbing at the stump and skidding tree lengths to the landing for processing eliminates this advantage. In salvage operations, concentration and disposal of the slash is an important insect control measure. If partial cuts are made, the slash may be concentrated in stand clearings before being burned.

Figure 5.—A typical stand after being thinned.

The quantity of logging residue left on an area can be used as a criterion of good or bad harvesting practices. Residue percentages derived from different bases are shown in table 16. The residue percentages of the original and residual stands indicate the need for and degree of slash disposal activities required. The large percentage of residues in unit II resulted from operator carelessness and his expectancy that the residues would be cleared and burned.

Conclusions

The results of this study indicate that thinning and salvage operations in young second-growth ponderosa pine stands can be done at a profit only if a sufficient amount of sawtimber can be removed. Recovery of other products, such as fence-[illegible]

Commonly available ranch and farm machinery proved to be well suited for harvesting work in young timber. Farm tractors can be fitted with grapples for whole-tree or log skidding and these machines can also be used to deck logs and pile slash. Properly used, the tractors were economical and efficient, and did a minimum amount of damage to residual trees.

Feller-bunchers were more efficient than chain saws in severing the trees, and grapple skidding was better than choker skidding. Full-tree skidding with processing at the landing did less damage to the stand than log skidding, as fewer stand entries were needed to remove all the small trees. Log making at the landing concentrated the tops and branches so that this material could be made into pulp chips or hog fuel. Tree-length skidding also permitted production of several different products—saw logs, posts, house logs—and concentration of these items at a single location.

Competent, well-trained personnel are required if small timber stands are to be profitably harvested.

Table 16.—Residues by cutting unit as a percentage of original and residual stand volumes and log volumes removed

Item	Cutting unit I	Cutting unit II	Cutting unit III	Cutting unit IV
Percent of original stand	4.9	11.3	4.5	9.5
Percent residual stand	24.8	96.0	12.7	49.9
Percent volume removed	6.6	14.6	7.5	13.2

STUDY 2

A second study, made in the same general area, was started in the fall of 1980 and extended through the winter to the following March. During this interval, 8 areas totaling about 134 acres of second-growth ponderosa pine were sanitized and thinned. Sanitation consisted of removing living and dead trees that showed signs of the presence of insects, holes, or pitch tubes on the stems, and thinning to improve the spacing between residual trees.

Procedure

Experience gained from earlier work in the same ponderosa pine stands was used to determine procedures adopted for this investigation. The selected procedure consisted of three tree-felling phases.

The first phase was to go through the stand with a three- or four-man crew. One crewmember used a chain saw to fell trees less than 5 inches d.b.h. The other crewmembers bunched the trees, butt ends together, for skidding.

The second phase was to use the feller-buncher to cut and pile the trees between 6 and 10 inches in stump-high diameter. A small and a large Melroe Bobcat, Models 825 and 1075, were used. The final phase was to fell with a chain saw the trees too large in diameter for the feller-buncher shear opening.

All trees were skidded with either a John Deere 440 skidder or various farm tractors fitted with rear-mounted, shop-built grapples. Tree lengths only were moved to the landing. At the landing the larger trees were cut into stud and saw logs and decked for later removal. Tops, branches, and smaller trees were chipped in a Morbark Model 12 Chiparvestor, and the fuel chips were discharged into 40-ft flat-bottomed pulp chip van. To utilize the chipper near capacity, the smaller trees were stockpiled in a near-vertical position at the landing (fig. 6). After chipping had started, the stockpiled trees were used to maintain a continuous flow of material to the chipper, supplementing the tops and branches from freshly skidded saw-log-size trees.

Figure 6.— Stockpiling of thinned trees at the landing.

The objective of the study was to determine the productivity and costs of this harvesting system. Productivity was measured by a physical count of trees cut in each of the three felling phases, by sampling the skidded bunches, and by recording the time needed to complete each operation. With the exception of the small hand-felled stems, the diameter at the butt end, d.b.h., length to a 6-inch diameter, and total length were recorded for each tree in the sampled bunch. Butt diameter and total length only were recorded for the small tree sample bunches. Total costs were calculated by using the machine and man-hours and the hourly cost of each. Prorating these costs permitted calculation of individual tree-felling cost and bunch-skidding cost. Chipping cost per unit was determined by recording the time necessary to fill a van of known capacity.

Values recovered from the areas were based on 200-ft^3 hog fuel units blown into the van at $16 each, stud logs at $80/M bd.ft. Scribner log scale, and saw logs at $164/M bd.ft. Scribner log scale. Log prices were for the material decked at the landing.

Results and Discussion

Hourly and daily rates for the different pieces of study equipment are shown in table 17. In addition, a $50 rate per day per man was used in computing the costs of felling, skidding, and processing individual trees as well as per-acre costs. Cost data for the individual study areas are shown in table 18.

As would be expected, per-acre cost for the various operations varied widely, reflecting the different stand and operating conditions. Hand thinning cost per acre ranged from $43.68 to $147.20, and the weighted average cost per acre was $86.12. Machine thinning cost per acre ranged from $7.99 to $87.65, and the weighted average cost was $32.25 per acre. The total skidding cost per acre, for all trees, ranged from $40.18 to $149.14, and the weighted average per-acre cost was $76.72. The total cost of producing chips, stud logs, and saw logs ranged from $102.99 to $498.09 per acre, and the weighted average cost was $166.45 per acre.

Income data and the net return per acre are shown in table 19. The total cost per acre ranged from $185.66 to $814.26. The income per acre from hog fuel ranged from $70.50 to $681.33, with a weighted average income of $219.09 per acre. Stud log income ranged from $33.60 to $468.27 per acre, and the weighted average income was $321.43 per acre. Sawtimber was obtained from five areas and the value of this product ranged from $43.74 to $210.46 per acre, with a weighted average of $150.31 per acre. Total per-acre income ranged from $226.95 to $919.35, and the weighted average income per acre was $648.50. Net return per acre ranged from a loss of $99.77 to a profit of $439.43, with a weighted average return of $308.80 profit.

In general, the value of the hog fuel was at least one-third and as much as 86 percent of the total per-acre costs. Income from the stud logs and saw logs provided most of the profit margin. The two areas that had a net loss per acre produced no saw logs.

Table 17.—Hourly and daily rates for various pieces of equipment used in thinning study

Machine	Cost per hour	Cost per day
	- Dollars --	
Chip Harvester Model 12[1]	32.00	200.00
John Deere 440 skidder	16.00	100.00
John Deere 2940 4WD tractor	7.50	55.00
Allis Chalmers 180 and Ford 7000 tractors	6.00	40.00
Melroe "Bobkitten" steer skid	6.25	55.00
Melroe Bobcat 1075 feller-buncher	15.00	100.00
Front end loader[2]	6.50	50.00
6x6 flatbed truck	6.50	50.00
Dump truck	3.00	20.00
Stock truck	3.00	20.00
Semi-tractor	13.00	100.00
Crawler tractors	13.00	100.00
Road grader	4.00	30.00
Husky heelboom loader	3.00	25.00
Fifth wheel trailer	1.50	10.00
Semi-trailer, 45 feet	2.25	18.00
Chain Saws	4.00 per day for saw only 10.00 per day for saw, gas, oil, etc.	
AC 2000 tractors	6.75	50.00

[1]Data for the first six machines include all fixed and variable costs, but exclude operator or labor costs

[2]Data for the other machines do not include fuel, lube, or minor repair costs

Table 18.—Costs of performing various harvesting operations on the eight study areas

Area	Hand thinning				Machine thinning			Sawtimber		Skidding	Processing (cost/acre)		
	Acres	No. trees	Cost/ stem	Cost/ acre	No. trees	Cost/ stem	Cost/ acre	Volume cut	Cost/ acre	Total cost/acre	Chipping	Stud logs	Saw logs
								M bd.ft.					
Gravel Pit	20.50	8,058	$0.19	$ 74.03	1,580	$0.25	$19.41	17,130	$2.52	$ 97.04	$138.30	$ 20.69	$1.26
Section 34	29.56	6,383	.20	43.68	3,565	.35	42.42	25,670	1.44	103.96	150.71	40.48	4.93
Airstrip A & B	5.35	1,087	.19	79.38	2,079	.22	87.65	—	—	149.14	387.37	110.72	—
Big Chip Pile	7.10	3,550	.19	94.87	325	43	19.65	—	—	61.44	114.08	37.34	—
Spring Creek	5.00	3,850	[illegible]	147.20	252	[illegible]	24.60	4,610	6.84	85.11	129.60	40.59	9.57
No Name Creek	18.00	12,277	.19	134.56	1,216	.32	21.75	15,140	6.67	80.66	146.25	23.23	9.17
Rifle Range	8.70	6,870	.15	120.83	148	.47	7.99	—	—	56.24	139.66	2.00	—
Crazy Gate	39.20	—	—	—	1,863	[illegible]	37.24	50,000	5.25	40.18	41.33	58.81	2.85
Weighted average cost/acre				86.12			32.25		4.05	76.72	[illegible]		

Table 19.—Per-acre income from the various products for the eight study areas

Area	Acres	Total cost/acre	Income per acre			Total income/ acre	Profit (or loss)/acre
			Chips	Stud logs	Sawtimber		
			Dollars				
Gravel Pit	20.50	353.25	225.00	260.80	138.60	624.40	271.15
Section 34	29.56	387.62	256.80	426.96	143.29	827.05	439.43
Airstrip A & B	5.35	814.26	681.33	238.02	—	919.35	105.09
Big Chip Pile	7.10	327.38	186.60	138.80	—	325.40	(1.98)
Spring Creek	5.00	443.51	215.85	231.20	151.80	598.85	155.34
No Name Creek	18.00	422.29	363.26	159.12	43.74	566.12	143.83
Rifle Range	8.70	326.72	193.35	33.60	—	226.95	(99.77)
Crazy Gate	39.20	185.66	70.50	468.27	210.46	749.23	563.57
Weighted average/acre		339.70	219.09	321.43	150.31	648.50	308.80

Conclusions

Results of the second study indicated that with suitable markets available within a reasonable distance, small-sized trees can be economically harvested and utilized. A three-step system that removed the smallest trees first and the largest trees last proved to be an efficient harvesting method. Grapple skidding with a modified farm tractor that permitted slope decking of the trees at the landing was a cost-effective procedure for operating the chipper near capacity.

The total weighted average cost per acre of felling, skidding, and processing the trees was $339.70. Most of the harvesting cost was covered by the value of the hog fuel, and the value of the saw logs provided a profit margin. The weighted average per-acre income from hog fuel was $219.09, for stud logs $321.43, and for saw logs $150.31. The weighted average total income per acre was $648.50, and the weighted average profit per acre was $308.80.

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Wood from salvage and thinning operations in second-growth stands in western National Forests constitutes a potential resource that may help alleviate present and future timber shortages. This report presents cost information and describes harvesting systems and machines that have satisfactorily and economically operated in such stands.

KEYWORDS: salvage thinning, logging systems, small tree utilization, second-growth timber stands, whole-tree chipping

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Campsite Conditions in the Bob Marshall Wilderness, Montana

David N. Cole

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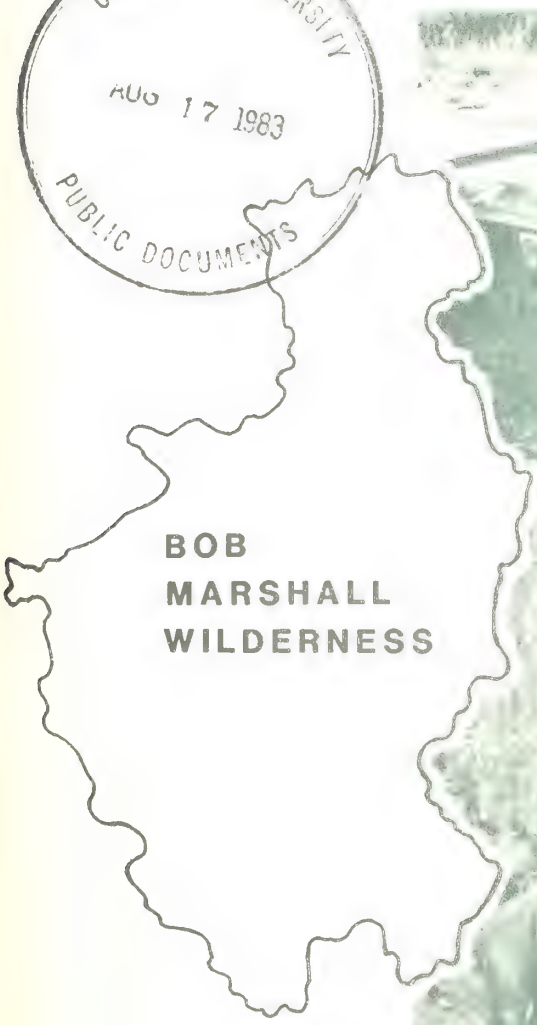

THE AUTHOR

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RESEARCH SUMMARY

Conditions were examined on campsites in low-to-mid-elevation forests and grasslands in the Bob Marshall Wilderness, Mont. Camp area, bare area, and the extent of tree damage were evaluated. Other changes were assessed by comparing campsites to comparable control sites. The changes estimated in this way were loss of tree seedlings, ground vegetation, and duff, increase in mineral soil exposure and compaction, change in species composition, and reduction in infiltration rates.

Trampling disturbance of groundcover vegetation and soils was similar in magnitude to what has been reported elsewhere. The unique features of these campsites were the large area that had been disturbed and the great number of damaged trees. Such damage is primarily a result of the prevalence of large parties with stock and the persistence of practices such as felling trees for tent poles and tying stock to trees.

Campsites used primarily by backpackers, sites used primarily by private stock parties, and sites used by commercial outfitters in the fall were compared. Certain types of impact, such as percentage of vegetation lost, were comparable on all three types of campsite. The types of impact that are most extreme on Bob Marshall campsites, however, are most pronounced on those sites used primarily by private stock parties and commercial outfitters.

Several management actions can be taken to reduce campsite damage. Most importantly, users must be educated about the damage resulting from felling trees and tying stock to trees. It would also be helpful to encourage the use of existing campsites in popular areas. In less popular areas, people could be encouraged to use undisturbed, resistant sites, such as many of the grasslands, to avoid seriously damaging any single site. Finally, in places that are frequently used by novice stock parties the Forest Service should consider providing corrals or hitchrails to reduce tree damage.

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Campsite Conditions in the Bob Marshall Wilderness, Montana

David N. Cole

INTRODUCTION

Of the recreational impacts occurring in wilderness, those on campsites are the most troublesome and complex to manage. The potential solutions to such problems are numerous, and it is seldom obvious which solutions are most appropriate or likely to be effective. Use rationing, limitations on length of stay or group size, concentrating campers on designated sites, dispersing campers among numerous sites, campsite closures, prohibition of wood fires, and visitor education are some of the techniques that have been used in an attempt to solve campsite problems. Too often the effects of such actions cannot be accurately predicted. Even more regretable, after actions have been taken it is seldom possible to evaluate their effectiveness because systems for monitoring changes in campsite condition are not in place.

In the western United States, most studies of campsite condition have been conducted at high elevations; therefore, the conclusions drawn may not be applicable to campsites at lower elevations. Furthermore, previous studies have not compared the condition of campsites that have been subjected to very different types of use. Such informational gaps provided the impetus for long-term monitoring of campsites in the Bob Marshall Wilderness, Mont., an area frequented by parties of backpackers, private individuals with packstock, and commercial outfitters and their clients. Specific purposes of this study were: (1) to document campsite condition for future monitoring; (2) to compare the condition of sites subjected to the three major categories of user; and (3) to test the hypothesis that low-elevation campsites are less fragile than high-elevation campsites. This report describes the study area, how the study was conducted, results of the study, and management implications.

STUDY AREA AND STUDY METHODS

The Bob Marshall Wilderness is located south of Glacier National Park, along the Continental Divide in Montana. At just over 1 million acres (408 000 ha), the Bob Marshall is one of the largest wildernesses in the Nation. User densities are moderately low (0.15 visitor-day/acre in 1981), although certain travel corridors and destinations do receive concentrated use. The area is unique in the high proportion of stock users and the importance of fall hunting. In 1970, two-thirds of all parties had packstock; about one-half of these were with outfitters. Over one-third of the use was in the fall, and about one-third of all parties hunted (Lucas 1980).

We examined 35 campsites within the Bob Marshall Wilderness, selecting sites located in various parts of the wilderness (fig. 1). Both forest and grassland sites were examined, but all sites were at relatively low elevations for a mountainous wilderness in the West—between 4,100 and 5,500 ft (1 250 and 1 675 m) (fig. 2). Although only well-established sites were studied, use ranged from the most frequently used sites to sites used only a few times per year. We examined six camps that were used almost exclusively by backpackers. The most numerous sites were those used predominantly by private parties with stock (called horse camps hereafter). These sites, of which we selected 24 for study, are used less frequently by backpackers and by roving commercially outfitted groups. We also examined five camps assigned to commercial outfitters. Most of these sites are off the main trails, and are mainly used in the fall as hunting base camps.

Each sample site consisted of both a campsite and an undisturbed control site nearby. From a fixed point close to the center of the campsite, we measured the distance to the edge of the campsite, and to the first significant amount of vegetation along each of 16 transects. This defined the campsite area and the area of the barren central core (bare area). Tree seedlings between 6 and 55 inches (15 to 140 cm) tall were counted within the camp area, excluding any untrampled "islands"; larger trees were counted within the entire camp area, including the "islands." Any human damage to trees was noted.

On each campsite, 15 quadrats, 3.28 by 3.28 ft (1 m by 1 m) square, were located along four transects. The transects originated at the center point and were oriented perpendicular to each other. The distance between successive quadrats decreased with distance from the center point, so that the central part of the site was not oversampled. In each quadrat, the canopy coverages of total ground vegetation, exposed mineral soil, each vascular plant species, and mosses and lichens as a group were estimated. Coverages were estimated, always by the same investigators, to the nearest percent if under 10 percent or, in 10 percent coverage classes, between 10 and 100 percent. The midpoints of each class were used to calculate means for each variable. Plot layout and measurements are fully described and illustrated in Cole (1982).

Soil compaction and depth of organic litter and fermentation (0) horizons (duff depth) were measured adjacent to each quadrat. Compaction was measured with a pocket soil penetrometer in the uppermost portion of the mineral soil after the organic horizons had been removed. Infiltration rates were measured with a double-ring infiltrometer, between 3 and 6 ft (1–2 m) from the center point along two of the transects. The rate that the first 0.39 inch (1 cm) entered the soil was called the instantaneous infiltration rate. After 2 inches (5 cm) had

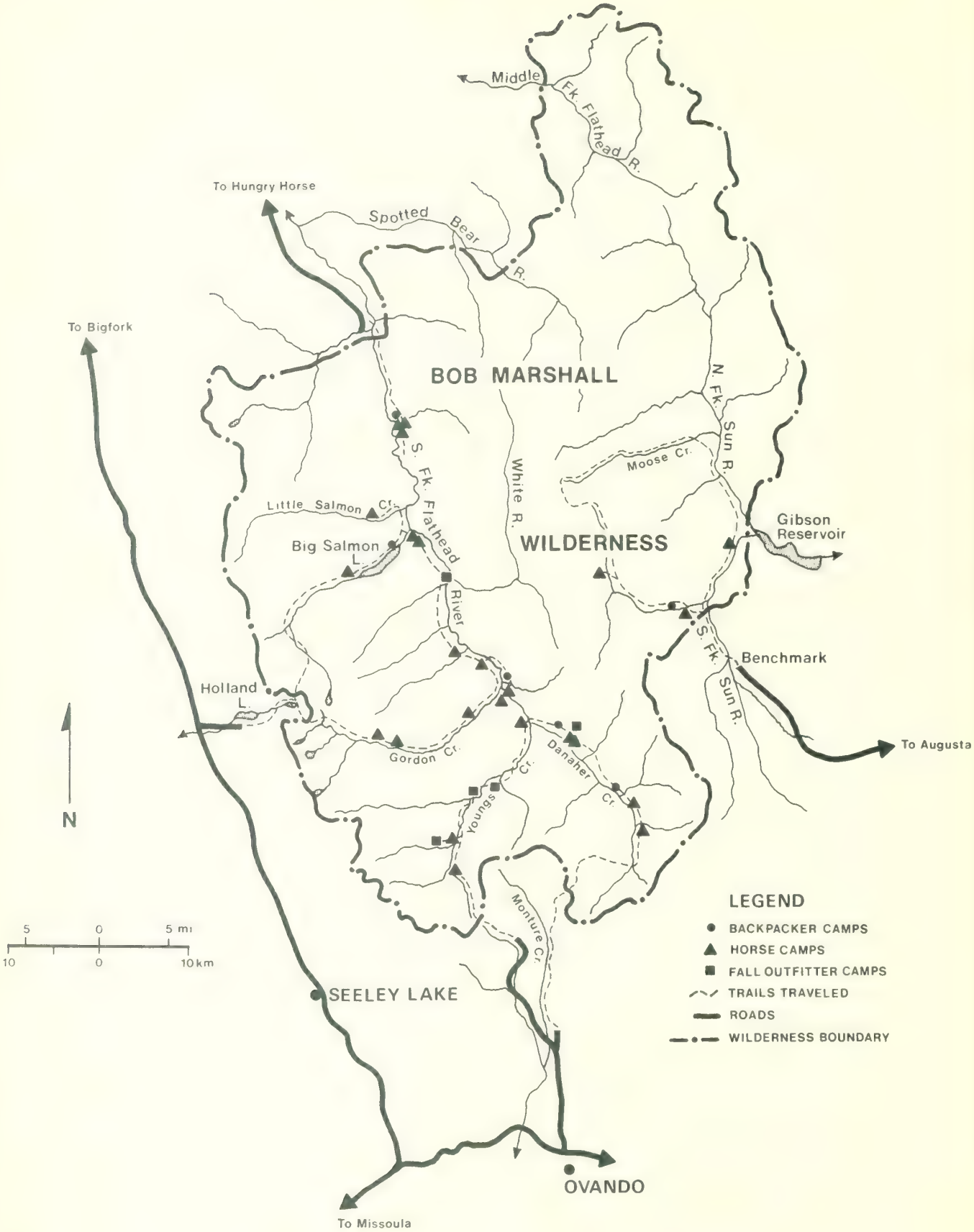

Figure 1.—Locations of sample campsites within the Bob Marshall Wilderness.

Figure 2.—The study campsites were located in forests and grasslands at relatively low elevations.

soaked into the soil, more water was added. The rate that the next 0.39 inch (1 cm) entered the soil was called the saturated rate. Both are expressed in centimeters per minute.

On the control plots, which usually varied in size between 165 and 330 ft^2 (50 and 100 m), we estimated the coverage of total vegetation, exposed mineral soil, each vascular plant species, mosses, and lichens for the entire plot. We counted numbers of seedlings and took 15 duff depth and penetration resistance measurements and two infiltration rate measurements.

On very large sites, where there were several discontinuous disturbed areas, usually holding areas for stock, we took detailed measurements in the central area used for cooking. Then we estimated the size of the entire disturbed area and assessed tree damage in this larger area.

The amount of change that has occurred is inferred from comparisons of campsites and controls. I calculated both absolute change—the difference between measurements on the control site and measurements on the campsite—and relative change—the absolute change expressed as a percentage of the measurement on the control site. Where control conditions are variable, relative change provides a more valid basis for site-to-site comparisons than either absolute change or current campsite conditions. Change in species composition was measured with the following coefficient of floristic dissimilarity:

$$FD = 0.5 \Sigma |p_1 - p_2|$$

where p_1 is the relative cover of a given species on the control plot, and p_2 is the relative cover of the same species on the campsite (Cole 1978).

Two different analyses were used to determine the statistical significance of results. The first analysis involved testing whether campsites were significantly different from controls. The Wilcoxon matched-pairs, signed-ranks test ($\alpha = 0.05$) was used to test the null hypothesis that campsite conditions were not significantly different from controls (Siegel 1956).

The second set of tests examined the differences between backpacker camps, horse camps and outfitter camps. The null hypothesis that conditions on each of these types of camp were identical was tested using the randomization test for two independent samples ($\alpha = 0.05$) (Siegel 1956). Randomly selected samples of 5 of the 6 backpacker sites and 5 of the 24 horse sites were compared with each other and with the 5 outfitter sites examined.

RESULTS AND DISCUSSION

How Much Change Has Occurred?

Campsite area on the 35 sites varied between 624 and 6,512 feet^2 (58 and 605 m^2) (table 1); the median site was 2,352 ft^2 (216 m^2). Most of the campsite area was vegetated; the median bare area was only 150 ft^2 (14 m^2). Some 23 of the 35 sites, however, had large areas away from the camping area that had also been disturbed, usually from holding packstock. About one-tenth acre (405 m^2) was disturbed on the median campsite. The largest site had a disturbed area of more than 2.5 acres (10,600 m^2).

On most campsites, all of the overstory trees have been damaged. Typically, about 15 percent of the on-site trees have been felled, another 55 percent are scarred with ax marks, nails, and so on, and the rest have had their lower branches broken off for firewood. Over one-half of these trees have also had their roots exposed, usually from the trampling of stock tied to their trunks.

The number of trees affected is sizeable, particularly when damage on the entire disturbed area—both campsite and stock-holding area—is considered. The median number of damaged trees was 63 per site, but on one site approximately 500 trees had been damaged. Particularly disturbing were the large number of trees that had been felled (median of 15 per site) and that had exposed roots (median of 28 per site). This is visually obtrusive, long-term damage (fig. 3). On many areas with no other evidence of use, tree damage identified the place as a former campsite. This damage is also cumulative—each year newly damaged trees are added.

Table 1.—Size of disturbance, tree damage, and change in species composition on all 35 campsites

Statistic	Camp area	Bare area	Disturbed area	Damaged trees	Scarred trees	Felled trees	Trees with exposed roots	Damaged trees	Scarred trees	Felled trees	Trees with exposed roots	Floristic dissimilarity
	Square meters			*Percent on camp area*				*Number on disturbed area*				*Percent*
Median	216	14	405	100	70	15	54	63	49	15	28	63
Range	58-605	0-291	58-10,600*	0-100	0-100	0-67	0-100	0-500*	0-300*	0-200*	0-100*	31-97

*The highest values are visual estimates rather than counts or measures.

Figure 3.—Cut trees provide evidence of human use long after trampled vegetation has recovered.

The long-term importance of tree damage is reinforced by the lack of tree reproduction on campsites. About three-fourths of the campsites have no tree reproduction at all, and reproduction is very low on the other sites (table 2). In the future we can expect reductions in tree density and the creation or expansion of nonforested areas used as campsites.

Although the barren central core of the campsite is typically small, trampling has affected groundcover over the entire site. The median campsite has only one-third the vegetation cover of its paired control. Several sites have lost over 90 percent of their original vegetation. The composition of the vegetation that does survive is very different from that on controls. The median floristic difference between campsites and controls (an index of change in species composition that can vary from no change—0 percent—to complete change—100 percent) is 63 percent (table 1).

To better understand the compositional changes resulting from trampling, I compared the relative cover of different growth forms on campsites and controls (table 3). The most pronounced change is the near elimination of shrubs and subshrubs (woody species other than trees) on campsites. Their median relative cover on controls was 21 percent, while their median relative cover on campsites was only 4 percent. Mosses and lichens have also been nearly eliminated on campsites. There has been a corresponding increase in the importance of graminoids (grasses and grasslike species) and forbs (herbaceous species other than graminoids) on campsites. Median relative cover values for graminoids were 29 percent on controls and 36 percent on campsites; for forbs values were 43 percent on controls and 51 percent on campsites.

To examine the response of individual species to trampling, I categorized the most common native species into those that are particularly resistant to trampling damage, those that are particularly susceptible, and those that are neither resistant nor susceptible. Less common native species are listed in the appendix. I also identified species that "invaded" campsites—species that are always found more frequently on campsites than controls and that often also provide more cover on campsites than controls (table 4). The invader list includes 27 introduced species (8 of which are annuals) and 12 natives (8 of which are annuals). Three of the four most abundant species on campsites are common domestic lawn species—*Poa pratensis* (Kentucky bluegrass), *Taraxacum officinale* (common dandelion), and *Trifolium repens* (white clover).

Table 2.—Soil and vegetation changes on all 35 campsites*

Statistic	Seedlings	Vegetation	[illegible]*	Duff	Penetration	[illegible]
	Stems/ha	[illegible]	[illegible]	*cm*	[illegible]	[illegible]
Campsite						
median	0	29	7.4	1.2	[illegible]	[illegible]
range	0–560	1–84	0.3–53.2	.05–4.4	1.7–4.5	[illegible]
Control						
median	600	85	0	[illegible]	[illegible]	[illegible]
range	0–7,342	65–100	0–5	0.2–11.0	[illegible]	[illegible]
Median absolute change	880	52	7.1	[illegible]	[illegible]	[illegible]
Median relative change (%)	100	66	[illegible]	45	[illegible]	[illegible]
Significance level	< 0.001	< 0.001	[illegible]	< 0.001	< 0.001	[illegible]

*Absolute change is the difference between c[illegible] control value. Significance was tested with a or[illegible]

Table 3.—Relative cover of growth forms on all 35 [illegible] controls

	Camps[illegible]		Control sites		
Growth form	Median	[illegible]	Median	[illegible]	[illegible]
Graminoids	36	7[illegible]	[illegible]	[illegible]	0.01
Forbs	51	[illegible]	[illegible]	[illegible]5	[illegible]
Shrubs and subshrubs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mosses and lichens	[illegible]	0–27	[illegible]	[illegible]	[illegible]

*Significance was tested with the Wilcoxon [illegible]urs, signed-ra[illegible]

Table 4.—Cover and frequency of campsite "invaders"*

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Agropyron repens[1]	7	3	2.9	3.0	3.3	1.6
Agrostis alba[1]	3	0	1.0	.0	2.3	.0
Arabis glabra[1]	3	2	.2	1.0	.2	.5
Bromus inermis[1]	3	2	1.7	6.3	2.8	2.8
Bromus tectorum[1,2]	1	0	.7	.0	.6	.0
Capsella bursa-pastoris[1,2]	11	0	.6	.0	1.6	.0
Cerastium arvense	8	1	1.2	.9	1.1	.3
Chenopodium album[1,2]	2	0	2.2	.0	2.9	.0
Collinsia parviflora[2]	5	1	.3	.4	.8	.2
Dactylis glomerata[1]	3	1	.7	.5	.8	.4
Descurainia richardsonii[2]	4	1	2.4	.5	6.9	.3
Epilobium paniculatum[2]	1	0	.2	.0	1.8	.0
Filago arvensis[1,2]	1	0	.2	.0	1.8	.0
Lappula redowskii[2]	2	0	.6	.0	1.6	.0
Lepidium densiflorum[2]	3	0	.1	.0	.4	.0
Linanthus septentrionalis[2]	2	1	.5	1.0	.6	.4
Lychnis alba[1]	2	0	1.4	.0	1.7	.0
Matricaria matricarioides[2]	4	0	1.3	.0	5.5	.0
Medicago lupulina[1,2]	3	1	2.7	2.0	4.0	1.2
Phleum pratense[1]	13	3	1.4	2.7	1.8	1.2
Plagiobothrys scouleri[2]	6	0	6.0	.0	10.3	.0
Plantago major[1]	12	0	.5	.0	1.0	.0
Poa annua[1,2]	4	0	3.6	.0	4.8	.0
Poa palustris[1]	1	0	3.0	.0	1.2	.0
Poa pratensis[1]	29	14	12.4	7.6	20.0	3.2
Polygonum aviculare[1,2]	5	0	2.4	.0	6.6	.0
Potentilla argentea[1]	1	0	.1	.0	.3	.0
Rumex acetosella[1]	2	1	1.6	2.0	1.5	.7
Rumex crispus[1]	3	1	1.7	.3	2.2	.1
Sagina saginoides	1	1	4.3	5.0	5.1	2.0
Stellaria calycantha	1	0	.7	.0	.9	.0
Stellaria longipes	2	0	1.2	.0	1.6	.0
Taraxacum officinale[1]	31	15	4.4	1.2	6.9	.6
Thlaspi arvense[1,2]	4	0	.3	.0	.5	.0
Tragapogon dubius[1]	1	0	1.0	.0	.6	.0
Trifolium pratense[1]	6	4	.6	.6	.6	.4
Trifolium repens[1]	20	14	4.0	2.9	5.9	1.4
Verbascum thapsus[1]	1	0	.2	.0	1.8	.0
Veronica serpyllifolia	3	2	.5	.8	.5	.3

*Species that are more common on campsites than on controls. Means are for the sites on which the species was found—not all 35 sites. The [1] indicates a nonnative species; the [2] indicates an annual.

Only nine of the native species commonly found on controls are resistant to trampling (table 5). These species have less cover on campsites than on controls, but they survive more often than their associates. Consequently, their relative cover is higher on campsites than on controls. The list includes three species of graminoid and various forbs, most of which have basal leaves, a characteristic that reduces susceptibility to trampling damage. One of these resistant species, *Xerophyllum tenax* (beargrass) is one of the more common understory dominants in middle and higher elevation forests throughout much of the Pacific Northwest and Northern Rocky Mountains.

Twenty-four common species were categorized as highly susceptible; their relative cover on campsites was much lower than on controls (table 6). Many of these species are shrubs, subshrubs, or tall, leafy-stemmed forbs. Three of these—*Vaccinium caespitosum* (dwarf huckleberry), *Arctostaphylos uva-ursi* (kinnikinnick), and *Thalictrum occidentale* (western meadowrue) are among the most common species on control sites. Sites with these species in abundance should be considered highly susceptible to vegetation loss, if used for camping.

Table 5.—Cover and frequency of common native species that are particularly resistant to damage*

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Agoseris glauca	7	6	1.2	1.7	1.7	0.8
Agrostis scabra	7	6	4.3	4.4	4.9	2.3
Carex rossii	14	6	5	1.1	1.7	5
Penstemon confertus/procerus	20	21	2.4	4.4	6.0	2.0
Potentilla gracilis	11	7	2.8	2.9	2.7	1.3
Smilacina stellata	11	14	1.0	3.3	3.2	1.5
Solidago missouriensis	6	8	1.3	3.4	5.0	1.7
Stipa occidentalis	12	11	4.9	13.4	9.4	6.2
Xerophyllum tenax	3	8	7	8.4	9.4	5.2

*Species that are less abundant on campsites than controls, but that have a much higher relative cover on campsites. Common species are those that are found on at least one-fourth of the sample sites. Means are for all sites on which the species was found—not all 35 sites. Some of the *Potentilla gracilis* may be *P. recta*, a nonnative species.

Table 6.—Cover and frequency of common native species that are particularly susceptible to trampling damage*

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Arctostaphylos uva-ursi	5	18	0.4	11.8	1.1	6.7
Aster conspicuus	11	19	.5	7.9	1.3	3.9
Campanula rotundifolia	4	14	.1	1.6	.1	.7
Danthonia intermedia	3	11	.2	6.6	.1	3.0
Elymus glaucus	4	9	.2	6.4	.3	3.2
Epilobium angustifolium	8	18	.2	1.8	.2	.9
Geum triflorum	4	7	.2	1.3	.2	.6
Juniperus communis	2	12	.1	3.3	4	1.7
Koeleria cristata	5	10	.5	6.1	.9	3.1
Lichens	2	10	.1	4.2	.1	2.1
Linnaea borealis	1	11	.1	8.4	.1	4.4
Lithospermum ruderale	2	9	.4	2.2	.5	1.0
Lupinus sericeus	5	10	.1	4.0	.3	2.1
Osmorhiza chilensis	4	8	.1	1.5	1	.6
Pachistima myrsinites	2	8	.1	2.9	.2	1.5
Potentilla arguta	4	9	.1	2.3	.2	1.1
Pyrola secunda	1	9	.1	3.1	.8	1.5
Rhamnus alnifolia	0	8	.0	2.6	0	1.1
Senecio pseudaureus	10	17	.4	6.0	1.2	2.7
Shepherdia canadensis	0	11	.0	2.7	0	1.4
Symphoricarpos albus	13	16	.6	8.7	2.1	4.8
Thalictrum occidentale	9	21	.4	9.9	1.2	4.4
Vaccinium caespitosum	8	9	.8	24.1	4.7	13.4
Viola adunca	5	8	.1	1.2	.3	.6

*Species with much lower relative cover values on campsites than on controls. Common species are those that occur on at least one-fourth of the sample sites. Means are for all sites on which the species was found—not all 35 sites

Table 7 lists common species that are neither resistant nor fragile. These include the most common plants on controls, mosses, *Calamagrostis rubescens* (pinegrass), and *Fragaria virginiana* (strawberry), as well as the least susceptible of the common shrubby species, *Berberis repens* (creeping Oregon grape), *Rosa* sp. (rose), and *Spiraea betulifolia* (shiny-leaf spirea).

In addition to removing vegetative cover, trampling also disturbs organic horizons, exposing the mineral soil beneath. Most control sites had no exposed mineral soil, while the median exposure on campsites was over 7 percent (table 2). The depth of the organic horizons (duff) decreased 45 percent, from median values of 0.8 inches (2.1 cm) on controls to 0.5 inches (1.2 cm) on campsites.

Trampling also compacts the soil. Penetration resistance increased over 70 percent, from median values of 2.2 kg/cm² on controls to 3.1 kg/cm² on campsites. Infiltration rates were reduced as a result of this compaction. Median instantaneous infiltration rates on campsites were less than one-third of those on controls and median saturated rates are only one-sixth of those on controls.

Table 7.—Cover and frequency of common native species that are neither highly resistant nor highly fragile*

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Achillea millefolium	26	25	1.0	2.9	1.5	1.4
Allium cernuum	10	17	.7	3.6	1.4	1.7
Anemone multifida	9	9	.2	2.6	.9	1.3
Antennaria microphylla/ umbrinella	11	19	.7	3.4	1.0	1.6
Arnica cordifolia/latifolia	9	14	.7	7.8	4.4	4.2
Aster foliaceous	12	10	1.0	4.4	2.4	2.1
Berberis repens	19	21	.6	6.0	1.9	3.2
Calamagrostis rubescens	15	22	2.9	29.7	8.2	15.8
Carex geyeri	5	10	1.4	9.5	3.4	5.0
Cirsium hookeriana	5	12	.4	2.6	.7	1.2
Disporum trachycarpum	3	7	.1	2.0	1.0	1.0
Fragaria virginiana	31	33	3.1	14.2	6.5	7.1
Galium boreale	18	22	1.0	4.6	2.3	2.3
Gentiana amarella	7	6	.1	.9	.2	.4
Heuchera cylindrica	6	6	.3	2.0	.6	1.1
Mosses	21	23	3.0	23.5	6.2	10.4
Rosa sp.	15	18	1.2	6.5	3.1	3.5
Sedum lanceolatum	6	6	.7	2.1	.8	.9
Senecio serra	4	10	.3	1.6	.5	.7
Spiraea betulifolia	6	15	.6	8.1	4.3	4.6

*Common species are those that occur on at least one-fourth of the sample sites. Means are for all sites on which the species was found—not all 35 sites.

How Do These Changes Compare to Those Found Elsewhere?

Changes on these lower elevation sites—4,100 to 5,500 ft (1 250 to 1 675 m)—can be readily compared with changes on sites in subalpine forests—7,050 to 7,800 ft (2 150 to 2 400 m) in the Eagle Cap Wilderness in Oregon because similar methods were used (Cole 1982). To a lesser extent they can also be compared with backcountry sites studied in detail in subalpine forests in the River of No Return Wilderness, Idaho (Coombs 1976), and the Mission Mountains Tribal Wilderness and Rattlesnake Wilderness, Mont. (Fichtler 1980), and with low-elevation forested sites in the Boundary Waters Canoe Area, Minn. (Frissell and Duncan 1965; McCool and others 1969). In none of these other study areas is horse use as predominant as it is in the Bob Marshall.

Disturbance of groundcover on the Bob Marshall sites is generally toward the lower bounds of the range found in other studies. The median area devoid of vegetation (14 m²) is much less than the bare area on Eagle Cap sites (87 m²), and the 66 percent loss of vegetation is considerably less than was found on Eagle Cap (87 percent) or Boundary Waters sites (85 percent). However, vegetation loss was slightly higher than was found on sites in the River of No Return and Rattlesnake Wildernesses. Thus the hypothesis that lower elevation sites in the Bob Marshall, with longer growing seasons, might be notably more resistant to vegetation damage than subalpine forests is incorrect. Instead there was more variation in resistance between plant communities within an elevational zone than between elevation zones. Subalpine forests with understories dominated by *Xerophyllum tenax*, as in the Rattlesnake Wilderness, are much more resistant than those with understories dominated by *Vaccinium scoparium*, as in the Eagle Cap Wilderness. In the Bob Marshall, several grassland sites lost less than 20 percent of their cover, while many of the forested sites with fragile understories lost more than 80 percent of their cover.

Despite the moderately low loss of vegetation cover, the change in species composition on Bob Marshall sites has been more dramatic than has been documented elsewhere. The inva-

sion of introduced species has been particularly pronounced. Exotics constitute almost 15 percent of the campsite flora and are the most abundant species on most campsites. This invasion of exotics is promoted by heavy use of packstock (manure and feed are important seed sources) and is generally lacking on subalpine forest sites.

The elimination of essentially all tree seedlings on campsites is a finding common to all studies and attests to the extreme vulnerability of tree seedlings to trampling damage.

The increase in exposed mineral soil on Bob Marshall campsites is similar to that found on Mission Mountains sites (6 percent), but is considerably less than that found elsewhere (15 percent in the Boundary Waters to 25 percent in the Eagle Cap). The percentage of reduction in duff depth (relative change) is also somewhat less—45 percent in comparison to 51 percent on Eagle Cap sites and 60 to 65 percent on Boundary Waters sites. More duff has been removed (absolute change) from the Bob Marshall sites, however, than from the Eagle Cap sites—0.28 inches (0.7 cm) compared to 0.12 inches (0.3 cm). Apparently, more organic matter is lost from the Bob Marshall sites, but because the organic horizons are so thick to start out with, exposure of mineral soil is much less.

In the Bob Marshall wilderness, penetration resistance typically increased 71 percent, which is less than has been found elsewhere: Rattlesnake, 89 percent; Mission Mountains, 139 percent; and Boundary Waters, 220 percent. This may reflect the cushioning effect of thicker organic horizons or, more likely, it merely reflects inherent differences in soil characteristics. For example, undisturbed sites in the Bob Marshall have a higher penetration resistance than the campsites in the Mission Mountains.

Reductions in infiltration rates, perhaps the most meaningful measure of the effects of soil compaction, are more pronounced on Bob Marshall sites than on Eagle Cap sites. Both instantaneous and saturated rates on Eagle Cap campsites were still more than one-half of the rates on controls. In contrast, instantaneous rates on the Bob Marshall campsites were less than one-third of controls and saturated rates on campsites were one-sixth of controls.

Although disturbance of ground vegetation and soil is neither unusually high nor unusually low, the large size of the Bob Marshall sites and the amount of tree damage is unique. The size of the disturbed area on the median Bob Marshall site (4,360 ft^2; 405 m^2) is about twice the size of sites in the Eagle Cap (2,077 ft^2; 193 m^2) and Boundary Waters (2,830 ft^2; 263 m^2). The size of the area used for cooking and camping is similar in all three areas; the difference is the addition, in the Bob Marshall, of a large area disturbed by stock.

Given the character of use in the area—two-thirds of the parties have stock—this may be unavoidable. But the high level of tree damage on these sites is avoidable. The **percentage** of damaged trees on the campsites is comparable to other situations. In fact, the percentage of trees that have been felled is less than on Eagle Cap sites. It is the **number** of damaged trees that is so high on Bob Marshall sites. Compared to a median of 12 damaged trees per site in the Eagle Cap, the median Bob Marshall site had 63 damaged trees and one site had about 500. The median Eagle Cap site had 4 felled trees and 3 trees with exposed roots. Median values for the Bob Marshall sites were 15 felled trees and 28 trees with exposed roots (fig. 4 and 5). This high level of damage is a result of tying horses to trees and felling trees for tent poles—practices that are unusually prevalent in the Bob Marshall—as well as collecting firewood from standing trees and malicious or thoughtless chopping of trees—practices that are also common in other areas.

Figure 4.—The large number of trees felled on this campsite is typical of Bob Marshall sites.

Figure 5.—Exposure of tree roots is unusually pronounced on most Bob Marshall campsites and persists even when ground vegetation has recovered.

How Do Impacts on Backpacker, Horse, and Outfitter Camps Compare?

Elsewhere I have suggested that the type of use a site receives and the behavior of the campers that use it will usually have more effect on amount of damage than how many people use the site (Cole 1981a). To some extent this is illustrated by certain types of impact being unusually pronounced on Bob Marshall sites despite relatively low levels of use compared to Eagle Cap and Boundary Waters sites. The importance of type of use is also suggested by a comparison of the condition of the backpacker, horse, and outfitter sites that were examined.

Before reporting the data, it is important to stress their limitations. Differences in campsite condition cannot be attributed entirely to differences in type of use. Amount of use differed greatly, with many horse camps receiving more use than outfitter camps, which received more use than the backpacker camps. The inherent ability of the sites to resist damage also varied. Generally, outfitter camps were located on most resistant sites and backpacker camps were located on least resistant sites. Finally, some backpackers and outfitters use private horse camps, and some backpackers and private horse parties use outfitter camps. Nevertheless, the nature of the differences between these types of sites suggests that the predominant type of use each site receives is the major determinant of amount of impact.

Campsite area is smallest on backpacker sites (fig. 6), being generally less than one-third the size of other sites (table 8). This difference is primarily a result of fewer large backpacking parties. The lack of a significant difference in the camp area of horse and outfitter camps is misleading because outfitter camps consisted of many dispersed tent sites that were generally not included in the camp area measure. Differences in bare area are not significantly different, but none of the backpacker sites had the large bare area that a few of the horse and outfitter sites did.

Figure 6.—A relatively small campsite mainly used by backpackers.

Table 8.—Size of disturbance in relation to type of use*

	Camp area			Bare area			Disturbed area		
Type of use	Median	Range		Median	Range		Median	Range	
	Square meters								
Backpacker	76	58-175	a	3	2-34	a	76	58-175	a
Horse	251	200-404	b	13	5-291	a	456	200-1,204	b
Outfitter	233	145-443	b	14	0-100	a	3,143	408-10,600	c

*Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples

The most pronounced differences are in the size of the disturbed area—the camp area plus other discontinuous disturbed areas. The median horse camp is 6 times larger than the median backpacker site. The median outfitter camp is 7 times larger than the horse camps and 41 times larger than the backpacker camps. These differences result from differences in party size (outfitter groups are generally larger than private horse groups, which are larger than backpacker groups), the addition of an area damaged by stock on the horse and outfitter camps, and a Forest Service policy of spreading out facilities on outfitter sites (fig.7).

Tree seedling loss is generally 100 percent regardless of the type of use (table 9). Damage to mature trees, however, is considerably more extensive on horse and outfitter sites. Essentially all trees on the campsites are damaged, but the number of such trees increases from a median of 5 on backpacker sites to 56 on horse sites and 100 on outfitter sites. A similar pattern applies to numbers of felled trees and trees with exposed roots, except that for these parameters the percentage of trees damaged is also lower on backpacker sites. Differences between horse and outfitter sites are not consistent enough to be statistically significant. The differences between backpacker sites and other sites are a function of size of the campsite, the need to hold stock on or adjacent to horse and outfitter camps, and the damaging practices of tying horses to trees and felling trees for tent poles (generally not done by backpackers because they carry their own tent poles) or for firewood.

Figure 7.—Semipermanent tent frames, woodpile, and kitchen facilities typical of outfitters' camp.

Table 9.—Tree damage on campsites in relation to type of use*

	Seedling loss			Damaged trees			Felled trees			Trees with exposed roots		
Type of use	Median	Range		Median	Range		Median	Range		Median	Range	
	----- Percent -----			---------- Number of trees in disturbed area ----------								
Backpacker	100	100	a	5	3-29	a	0	0-8	a	1	0-4	a
Horse	100	92-100	a	56	21-180	b	8	0-33	b	25	10-38	b
Outfitter	100	100	a	100	23-500	b	15	3-250	b	37	13-100	b

*Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples. Seedling loss is relative change.

As was the case with bare area and seedling loss, there are no significant differences between backpacker, horse, and outfitter camps in the amount of surviving vegetation cover (table 10). There are also no differences in absolute or relative vegetation change. There are, however, some small, but statistically significant, differences in the amount of change in species composition. Backpacker sites have experienced less change than horse sites. Outfitter sites have the highest floristic dissimilarity value (76 percent), but they cannot be distinguished statistically from either backpacker or horse sites.

The most pronounced vegetational difference is in the degree to which these sites have been colonized by introduced and annual species (table 11). Introduced species account for only 5 percent of the cover on backpacker sites compared with 43 percent on horse sites and 61 percent on outfitter sites. Annuals, which are very rare in undisturbed places, are absent on most backpacker and horse sites but comprise 17 percent of the cover on outfitter sites.

Soil exposure generally increases from backpacker sites (5 percent) to horse (9 percent) and outfitter sites (33 percent). This corresponds with a gradient in duff depth from backpacker sites (0.9 in, 2.2 cm) to horse (0.5 in, 1.2 cm) and outfitter sites (0.1 in; 0.2 cm) (table 12). On Eagle Cap campsites, these are the types of change that were most aggravated by increases in amount of use. Thus these differences may reflect heavier use of horse and outfitter sites as well as differences in type of use.

Differences in penetration resistance on the three types of sites were not statistically significant. Penetration resistance values were highest on horse sites, and this difference is reflected in significantly slower infiltration rates on horse sites than on either backpacker or outfitter sites. All of these differences between types of sites are less pronounced than differences between any of these sites and controls, however.

Table 10.—Groundcover conditions on campsites in relation to type of use*

	Vegetation cover			Floristic dissimilarity			Soil exposure		
Type of use	Median	Range		Median	Range		Median	Range	
	Percent								
Backpacker	26	10-59	a	62	31-72	a	4.6	0.7-13.3	a
Horse	33	6-45	a	69	63-89	b	9.3	.7-39.1	b
Outfitter	30	13-80	a	76	48-97	a,b	32.9	11.9-44.5	c

*Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples.

Table 11.—Relative cover of introduced and annual species in relation to type of use*

	Introduced species			Annual species		
Type of use	Median	Range		Median	Range	
	Percent					
Backpacker	5	1-14	a	0	0-4	a
Horse	43	0-58	b	1	0-9	a
Outfitter	61	15-82	c	17	1-60	b

*Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples.

Table 12.—Soil condition on campsites in relation to type of use*

	Duff Depth			Penetration resistance			Infiltration rates: Instantaneous			Infiltration rates: Saturated		
Type of use	Median	Range		Median	Range		Median	Range		Median	Range	
	cm			kg/cm²			cm/min					
Backpacker	2.2	1.1-4.4	a	2.6	2.3-4.3	a	1.0	0.5-3.3	a	0.3	0.2-0.7	a
Horse	1.2	.1-2.1	b	4.0	2.1->4.5	a	.1	.1-.5	b	.07	.04-.1	b
Outfitter	.2	.1-.5	c	3.6	3.1-4.2	a	.8	.1-1.5	a	.2	03-.6	a

*Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples.

MANAGEMENT IMPLICATIONS

My initial hypothesis that impacts on these relatively low-elevation campsites might be much less severe than those found elsewhere proved to be false. Impacts resulting from trampling—loss of vegetation cover and organic horizons, and compaction of soil—were not very different from what has been found elsewhere. Vegetation loss is moderately low, but this is a result of the dramatic colonization of these sites by nonnative species. The situation is similar to many auto camp and picnic areas, where loss of vegetation cover is reduced by an invasion of introduced species (LaPage 1967; Brown and others 1977). Exposure of mineral soil is also low, but this reflects unusually thick organic horizons to start with. The amount of organic material lost as a result of trampling is as great here as elsewhere.

Instead these sites proved in some ways to be damaged to an unusually high degree, primarily as a result of the high proportion of large parties with stock and the prevalence of certain camping practices. For individual campsites, as opposed to campgrounds composed of numerous clustered sites, these camping areas are unusually large, and they have experienced exceptionally widespread tree damage.

A certain amount of this damage must be accepted. In fact, the largest campsites are the outfitter camps and a major reason for their large size is a Forest Service policy that encourages outfitters to spread their facilities. Aside from reevaluating this policy, the only ways to reduce the size of these areas are to cut back on party size (current party size limits are 15 hikers or riders and 35 head of stock) and to provide smaller holding areas for stock—hitchrails or corrals. This latter suggestion is likely to be most effective, particularly in areas that are frequently used. It would have the added positive effect of reducing the need to tie stock to trees, thereby cutting back on the exposure of tree roots. More visitors to the Bob Marshall considered pole corrals to be desirable than undesirable (Lucas 1980), and they have already been built in certain areas. On the other hand, they should be built only where absolutely necessary because over one-third of the visitors surveyed considered them to be undesirable.

Much of the trampling damage must also be accepted. Damage to vegetation and soil is only moderate and is the inevitable result of use. Vegetation loss, in particular, is as pronounced on backpacker sites as on horse camps. Because backpacker sites are less frequently used than horse sites, this suggests that neither reducing amount of use nor changing type of use is likely to substantially reduce trampling damage. The most effective means of minimizing these impacts is to influence where people camp.

Of the campsites examined, trampling damage was least pronounced on the grassland sites. The median vegetation loss on seven campsites located either in grasslands or open forests with a grassy understory was only 20 percent; the greatest loss on a grassy site was only 48 percent. In contrast, the median loss on six sites located on the *Abies lasiocarpa/Linnaea borealis* (subalpine fir/twinflower) habitat type (Pfister and others 1977) was 62 percent, and on seven sites located on the *Pseudotsuga menziesii/Symphoricarpos albus* (Douglas-fir/snowberry) habitat type was 66 percent. Vegetation loss was particularly pronounced on the *Abies lasiocarpa/Vaccinium caespitosum* (subalpine fir/dwarf huckleberry) habitat type; the median loss on 7 sites was 84 percent. Thus grassland sites here, as elsewhere (Weaver and Dale 1978; Cole 1981b), are the most resistant to damage (fig. 8). The lists of resistant and sensitive species (tables 5–7) can be used to judge site resistance.

In areas that are frequently used, impacts might be minimized by encouraging camping on already well-worn sites. It is particularly important for parties with a high potential for causing damage—parties that are large, have packstock, and build campfires—to use well-worn sites rather than create new campsites. As mentioned before, in some popular areas building hitchrails or a corral would concentrate stock damage within a campsite. In such areas, choosing a campsite in a resistant location is less important than using existing campsites and choosing sites that are out of the way of other parties. Campers should still avoid particularly sensitive sites, however.

In less frequently used areas, impacts might be minimized by encouraging parties to spread out among a large number of resistant campsites so that no site is used often enough to show evidence of use. This is particularly effective in grasslands or on areas without vegetation—sites that are resistant to damage. Visitors should be able to select sites that show no evidence of previous use and to leave little trace of their having used the site. Parties that are not prepared to do this should use well-worn sites. Obviously used but lightly impacted sites should be avoided because they will deteriorate quickly with increased use.

In the Bob Marshall, damage to trees is more serious than trampling damage. This damage is avoidable and unnecessary. Visitors should be educated so that they will not (1) hack and carve trees, hammer nails into trees, or break off branches for firewood; (2) cut down standing trees—dead or alive; or (3) tie stock to trees. These are the actions that have damaged Bob Marshall sites to an unusual extent.

Figure 8.—Early-season photograph illustrating yearly vegetation recovery on resistant grassland campsites.

The purpose of not doing these things is to leave as little evidence of human use as possible. The ecological effects of tree damage are not highly significant. Very few trees are mortally wounded and the number of trees damaged, when compared to all the other trees, is of little significance. The problem is that at almost every campsite there is abundant evidence of use and what many consider to be abuse. Given the intent and spirit of the Wilderness Act, to preserve natural conditions, "with the imprint of man's work substantially unnoticeable," every visitor should strive to avoid leaving evidence of his presence.

Hacking or felling trees is prohibited in many wildernesses. Hacking trees, like littering and other thoughtless behavior, can be reduced by telling people why they should not do it. Nails are hammered into trees to provide campsite conveniences, such as clotheslines and places to hang things. It will probably be difficult to convince visitors that such conveniences are not appropriate in wilderness. The same is true of breaking branches off trees or felling standing trees for firewood. Visitors will need to accept the inconvenience of walking a bit farther to find downed wood rather than deface standing trees.

It will be even more difficult to change the time-honored practices of felling trees for tent poles and tying horses to trees. Such practices did not create serious problems when few parties ventured into the woods. In recent years, the need to minimize the impacts resulting from these practices has been well recognized, but managing agencies have had little success in controlling them.

Several wildernesses prohibit both of these practices. In the Bob Marshall, where this camping style is traditional, education is probably a more appropriate vehicle for change. Many parties could probably be convinced to use the standard lightweight tents that are used by backpackers and are prevalent in most wildernesses. Although they provide fewer of the comforts of home, they are lighter and more compact than canvas tents. Where condoned by the Forest Service, poles should be stored in plain sight, so others will not cut new ones. For this to work, other users need to be taught that cutting and storing poles is appropriate in the area, so they should not be thrown away or burned for firewood. This may be difficult since in most other areas visitors have been taught that this is not appropriate. People felling trees for poles should cut them away from camps and trails where the stumps that remain are not visually obtrusive.

I have suggested that providing corrals or hitchrails at the most popular campsites would partly solve problems resulting from tying stock to trees (fig. 9). These have already been built in a few places in the Bob Marshall. While such facilities do provide a visitor convenience, they are primarily there for resource protection and can be justified on those grounds.

If such facilities are provided, it might also be desirable to inform visitors, both at trailheads and on maps, of where these facilities are located. This information will allow people that are bothered by such facilities to go elsewhere or at least to know what to expect. It will also direct novices to these sites. This is particularly important because novices, especially those with stock that have had little experience with wilderness travel, have the greatest potential to inflict damage. Although total use of the site is likely to increase, per capita impact on the site should be reduced by the protective facilities provided and unprotected sites elsewhere will be used less frequently. Protective measures may need to be taken, however, to mitigate other effects of increased use, such as increased litter or human waste problems.

Figure 9.—Hitchrails confine packstock trampling to a small area and avoid damage resulting from tying stock to trees.

In most places, such facilities cannot be provided. Stock parties visiting such areas should be prepared to use restraining techniques other than tying horses to trees. Miller (1974) and the USDA Forest Service (1981) provide excellent suggestions on effective stock-holding techniques that have less impact on the land. Hobbling is the best technique if stock are properly trained. Stock can also be tied with halter ropes to a hitchline tied, above the horse's head, between two trees. If a cut pole is available, a hitchrail can be made by tying the pole between two trees. Picketing and staking are potentially damaging; these practices should be avoided unless great care is taken to avoid trampling damage and overgrazing.

The keys to improved management of campsite impacts in the Bob Marshall are in decreasing order of importance, educating visitors on minimum impact camping techniques, influencing where people camp, and providing stock-holding facilities in selected locations. Limiting use would contribute little to improvement in conditions, although a reduction in party size, particularly in the allowable number of stock, could lead, in time, to a significant reduction in the size of these large campsites. With such programs in place, it should be possible to avoid further tree damage and to confine serious trampling damage to the few frequently used places where such damage cannot be avoided. Nevertheless, the effectiveness of any program implemented should be evaluated by making periodic inventories of the number of campsites and their condition.

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APPENDIX

Cover and frequency of uncommon species on campsites and controls.

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Acer glabrum	0	1	0.0	1.0	0.0	0.7
Actaea rubra	0	2	0	1.0	0	.5
Agastache urticifolia	0	1	0	10.0	0	5.3
Agropyron caninum	5	5	1.5	3.1	1.9	1.5
Agropyron spicatum	1	1	3	5.0	9	2.9
Agrostis exarata	0	1	0	3.0	.0	1.1
Amelanchier alnifolia	1	6	3	2.3	2.9	1.6
Angelica arguta	1	4	1	2.3	2	1.0
Antennaria racemosa	3	5	.3	2.7	8	1.3
Apocynum androsaemifolium	0	2	0	7.0	0	4.0
Arabis holboellii	2	1	1	3	2	2
Arenaria congesta	1	1	1.2	4.0	1.3	2.1
Arenaria macrophylla	2	5	.3	3.0	2.2	1.4
Artemisia ludoviciana	0	1	0	5.0	.0	1.9
Artemisia tridentata	0	1	0	1.0	.0	4
Aster chilensis	2	4	4	4.3	1.0	2.2
Aster laevis	1	2	7	4.5	1.7	2.3
Aster modestus	0	1	0	5.0	0	2.2
Astragalus alpinus	4	2	2	2.4	6	1.1
Astragalus robbinsii	0	4	0	2.0	0	1.1
Bromus carinatus	0	4	0	11.5	.0	7.5
Bromus vulgaris	4	7	1.0	6.9	3.8	4.0
Calamagrostis canadensis	0	2	0	6.5	.0	2.7
Calochortus apiculatus	3	6	.5	2.0	.6	1.0
Carex concinnoides	3	9	.1	2.3	3	1.2
Carex filifolia	1	0	5.3	0	4.2	0
Carex hoodii	5	2	3.9	6.0	3.9	3.4
Carex limnophila	1	0	1.1	.0	1.4	0
Carex microptera	3	1	1.8	3.3	2.4	1.3
Carex xerantica	1	0	1.3	.0	1.8	.0
Castilleja miniata	1	1	1	1.0	2	.6
Ceanothus velutinus	0	1	0	1.0	.0	.8
Chimaphila umbellata	0	3	0	1.0	0	7
Clematis ligusticifolia	3	4	.7	2.6	1.9	1.1
Clintonia uniflora	0	1	0	25.0	0	14.4
Collomia linearis	2	2	.7	1.0	.8	.5
Corydalis aurea	1	0	.1	0	1.1	.0
Crepis atrabarba	2	2	5.6	8.0	5.9	4.9
Deschampsia elongata	2	2	0.7	2.7	1.7	1.0
Epilobium watsonii	2	2	1	.5	3	.3
Equisetum arvense	3	4	6	14.0	4.1	5.5
Equisetum hyemale	0	1	.0	2.0	0	1.1
Equisetum laevigatum	1	1	3	10.0	.5	4.3
Erigeron compositus	1	0	1.0	.0	.8	.0
Erigeron glabellus	2	1	.7	1.5	1.0	1.0
Erigeron speciosus	6	6	.6	2.1	1.0	1.1
Eriogonum umbellatum	2	4	.4	2.0	.4	.9
Erythronium grandiflorum	4	3	.5	2.0	4.6	1.0
Festuca idahoensis	2	4	1.6	5.4	1.3	2.2
Festuca occidentalis	0	1	0	25.0	0	13.4
Festuca scabrella	1	6	.1	11.2	1	5.9
Gaillardia aristata	0	2	0	1.0	0	.5
Galium triflorum	1	5	.1	2.8	.3	1.2
Gentiana calycosa	0	2	.0	1.0	.0	5
Geranium viscosissimum	4	4	.2	2.2	5	9
Geum macrophyllum	4	3	.5	2.4	1.1	1.1
Goodyera oblongifolia	0	3	0	1.3	.2	6
Habenaria unalascensis	0	1	.0	2.0	.0	.7

Appendix.—(con.)

Species	Frequency of occurrence		Mean cover		Mean relative cover	
	Camps	Controls	Camps	Controls	Camps	Controls
	Number		Percent			
Hedysarum boreale	1	1	.1	7.0	.2	3.0
Hedysarum occidentale	0	1	.0	3.0	.0	1.7
Heracleum lanatum	0	5	.0	4.0	.0	2.1
Hieracium albertinum	2	4	.3	1.4	.4	.7
Hieracium albiflorum	4	3	.8	1.0	1.4	.7
Juncus balticus	1	0	.1	.0	1.1	.0
Juncus confusus	1	2	.1	1.0	.1	.4
Lomatium triternatum	2	1	.2	1.0	.2	.4
Lonicera involucrata	0	3	.0	6.3	.0	3.3
Lonicera utahensis	0	5	.0	3.2	.0	1.5
Luzula campestris	1	0	3.7	.0	2.9	.0
Luzula hitchcockii	0	1	.0	4.0	.0	2.8
Melampyrum lineare	0	1	.0	1.0	.0	.8
Melica subulata	1	3	.1	3.0	.1	1.4
Menziesia ferruginea	0	4	.0	7.8	.0	5.0
Mitella breweri	0	2	.0	3.0	.0	1.6
Mitella nuda	0	1	.0	10.0	.0	3.9
Muhlenbergia filiformis	1	1	1.5	5.0	1.9	2.0
Osmorhiza occidentalis	2	2	1.7	1.0	2.2	.4
Oxytropis campestris	1	1	7.1	1.0	5.8	.3
Oxytropis splendens	1	0	.2	.0	.3	.0
Pedicularis contorta	0	2	0.0	3.5	0.0	1.7
Phleum alpinum	1	0	.9	.0	.7	.0
Poa juncifolia	1	0	8.3	.0	11.3	.0
Poa nervosa	1	1	.5	15.0	1.8	8.7
Poa sandbergii	0	1	.0	8.0	.0	3.0
Polemonium pulcherrimum	2	1	1.7	1.0	11.4	.6
Potentilla fruticosa	1	7	.3	4.0	.4	2.0
Prunus virginiana	0	1	.0	3.0	.0	1.2
Pyrola chlorantha	1	2	.1	4.5	.3	2.5
Pyrola picta	0	1	.0	1.0	.0	.6
Pyrola uniflora	0	1	.0	1.0	.0	.4
Ranunculus uncinatus	2	1	1.0	1.5	1.2	.6
Ribes lacustre	1	5	.1	1.8	.1	.9
Rubus idaeus	0	1	.0	1.0	.0	.6
Rubus parviflorus	0	2	.0	2.5	.0	1.5
Salix scouleriana	0	1	.0	15.0	.0	8.8
Senecio canus	3	3	.1	1.4	.2	.7
Senecio integerrimus	5	2	.2	2.8	.6	1.3
Senecio triangularis	0	4	.0	10.3	.0	5.4
Sitanion hystrix	0	1	.0	2.0	.0	1.2
Smilacina racemosa	1	3	.1	.8	.1	.4
Sorbus sitchensis	0	2	.0	2.0	.0	.9
Stipa richardsonii	2	4	2.4	9.0	4.2	4.4
Tiarella trifoliata	1	2	.1	1.7	.2	1.1
Trisetum spicatum	0	1	.0	2.0	.0	1.2
Urtica dioica	1	1	.3	2.5	.4	1.4
Valeriana sitchensis	0	2	.0	1.0	.0	.7
Vaccinium globulare	3	4	.3	14.3	2.9	9.7
Vaccinium scoparium	5	4	.5	7.8	1.7	4.4
Veratrum viride	1	1	.1	2.0	7.7	1.4
Viola glabella	0	2	.0	2.5	.0	1.1
Viola orbiculata	2	6	.1	4.5	1.5	2.2

Cole, David N. Campsite Conditions in the Bob Marshall Wilderness, Montana. Res. Pap. INT-312. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 18 p.

The condition of campsites was examined in the Bob Marshall Wilderness, Montana. The amount of change that has occurred on these sites was inferred by comparing campsites with comparable control sites. Trampling disturbance—loss of vegetation, exposure of mineral soil, and compaction of the soil—was generally comparable to that found in other backcountry areas. Campsites were unusually large, however, and tree damage was severe. Such impacts were particularly pronounced on sites used by outfitters and large parties with stock. Actions for reducing damage are suggested.

KEYWORDS: ecological impact, campsites, wilderness, backcountry management, outfitters, packstock, Montana, Bob Marshall Wilderness

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